An Examination of How Load and Impulse Generated During the Jettisoning of a Simulated S-92 Push-Out Window are Related to Performance Success

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Abstract

Each year worldwide, helicopters transport millions of oil and gas workers to ocean-based oil platforms. While the vast majority of these flights are successful, helicopter ditchings do occur every year. When a helicopter ditches, passengers must egress from the fuselage through either a designated emergency exit or an in-cabin push-out window. Striking the in-cabin push-out window with a hand or elbow requires the generation of sufficient power, impulse, and force to successfully jettison the window. This study undertook an analysis of a secondary dataset to determine how load and impulse, generated during a jettison attempt, influenced the likelihood of successfully jettisoning a simulated in-cabin push-out window. The window simulated the Sikorsky S-92, a transport helicopter used to fly passengers to offshore installations. Participants attempted to jettison the simulated window in three different simulator conditions (in air in normal orientation, in water at 120˚ orientation and in water at 180˚ orientation). During the testing, three independent variables were controlled: seat type (normal [N], stroke [S], or aisle [A]), window strike location (lower near [LN], lower far [LF], upper near [UN] or upper far [UF]), and strike type (static hand [SH], dynamic hand [DH], or dynamic elbow [DE]). A total of six unique combinations were tested in all three conditions. The results indicated that load was significantly different between the dry and wet conditions for the NUFDH, SUNDH, NLFDE, and ALNDH. Impulse data also revealed that there was a significant difference between the dry and wet conditions for the NUFDH, SUNDH, NLFDE, SLNDE, and ALNDH. It was concluded that the magnitude of the load and impulse applied to the simulated window are important determinants of performance success.

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List of Abbreviations and Symbols

ALNDH	Aisle Lower Near Dynamic Hand
ALNSH	Aisle Lower Near Static Hand
ANOVA	Analysis of Variance
CAA	Civil Aviation Authority
CSEP	Canadian Society for Exercise Physiology
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
FAR	Federal Airworthiness Regulations
FSSC	Falck Safety Services Canada
HUET	Helicopter Underwater Egress Training
KG	Kilograms
KG*S	Kilograms per Second
METS™	Modular Egress Training Simulator
NTSB	National Transportation Safety Board
NLFDE	Normal Lower Far Dynamic Elbow
NUFDH	Normal Upper Far Dynamic Hand
PFP	Push-Out Force Plate
RFD	Rate of Force Development
SLNDE	Stroke Lower Near Dynamic Elbow
SUNDH	Stroke Upper Near Dynamic Hand
TC	Transport Canada
TSBC	Transportation Safety Board of Canada
UKCS	United Kingdom Continental Shelf

1.0 Introduction

1.1 Background Information

In 2010, nearly 124,000 helicopter flights transported approximately one million passengers to offshore installations on the United Kingdom Continental Shelf (UKCS) (United Kingdom Offshore Oil and Gas Industry Association Limited, 2011). In the same year, 938,000 flights transported over two million passengers to offshore installations in the Gulf of Mexico (Helicopter Safety Advisory Conference, 2014). While the vast majority of these flights successfully reach their destination, each year, accidents and incidents do occur. An accident is defined by National Transportation Safety Board (NTSB, 2011) as "an occurrence associated with the operation of an aircraft…in which any person suffers death or serious injury or in which the aircraft receives substantial damage (p. 625)". An incident is defined by the NTSB as "an occurrence other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operations" (p. 625).

Statistical reporting reveals that helicopter accidents associated with the transportation of oil and gas passengers actually occur on a relatively frequent basis. For example, in the Gulf of Mexico, the helicopter accident rate for 2013 was 0.98 per 100,000 flight hours and was actually lower than the 29-year average of 1.65 accidents per 100,000 flight hours (Helicopter Safety Advisory Conference, 2014). Between the years 1981 and 2010, 76 accidents (2.6/year) involving the transportation of passengers to installations on the UKCS were reported (United Kingdom Offshore Oil and Gas Industry Association Limited, 2011).

While it is important to understand the definition of an accident and an incident, water impacts, survivable water impacts and ditchings are more relevant to this thesis. A water impact is “unintentional contact with water or exceeding the demonstrated ditching capability for water entry.” (EASA, 2016 p. 9). A survivable water impact is “a water impact with a reasonable expectancy of no incapacitating injuries to a significant proportion of persons inside the rotorcraft, and where the cabin and cockpit remain essentially intact.” (EASA, 2016 p. 9). Finally, a ditching is “an emergency landing on water, deliberately executed in accordance with rotorcraft flight manual (RFM) procedures, with the intent of abandoning the rotorcraft as soon as practicable.” (EASA, 2016 p. 8). Numerous factors may lead to the flight crew initiating a ditching. These may include: mechanical failure, pilot error and erratic weather conditions (Baker, Shanahan, Haaland, Brady & Li, 2011).

Factors that influence occupant survivability of a ditching event have been extensively examined. These include: warning time (Brooks, MacDonald, Donati & Taber 2008), fuselage orientation (Brooks et al., 2008; Clifford, 1996), time at which the event occurs (Baker et al., 2006; Taber & McCabe, 2006), and breath-holding capacity (Cheung, D’Eon & Brooks, 2001; Taber et al., 2015). While previous research has provided insight into how these factors influence the survivability of the event, it is critical to understand that for the most part, passengers on board the ditched rotorcraft have little control over factors associated with the event.

To egress from a ditched rotorcraft, passengers must pass through an opening in the fuselage of the rotorcraft. On a helicopter such as the Sikorsky S-92, the helicopter type which is the focus of this study, these openings are of two different varieties. The first is an emergency exit. Emergency exits must conform to a series of strict regulations (Section 2.5) that are laid out by regulatory bodies such as the Federal Aviation Administration (FAA), Transport Canada (TC) and the Civil Aviation Authority (CAA). The second type of opening is an in-cabin push-out style window. The Sikorsky S-92 is equipped with windows that push-out out to produce an additional egress opening in each row of passenger seating that does not have an emergency exit in it. Of significance to this thesis is the 10 push-out windows on the Sikorsky S-92 not regulated by the FAA, CAA and/or TC. If the window meets the required size (Section 2.5) to be considered one of Type *I-IV*, then it is considered an emergency exit and is regulated as such. However, if the window does not meet the required size to be considered an emergency exit, then it is considered to be a supplementary egress opening.

This study analyzed a secondary dataset that recorded the factors that influence the jettisoning of an S-92 push-out window in a simulated environment. The analysis of the secondary dataset examined how load and impulse, applied to an S-92 push-out window during a jettison attempt, influenced the likelihood of success for the jettison task. Data were collected both in a dry and wet condition using a custom push-out force plate and a Modular Egress Training Simulator (METS™) Model 50B. The participants were tested using three different strike types (a static hand push, a dynamic elbow strike, and a dynamic hand strike) and failure rates where determined for six individual trials.

1.2 Research Question and Hypotheses

The research question for this study was: "How does the load and impulse, generated during an attempt to jettison a simulated S-92 push-out window, influence the likelihood of success?" To answer the research question, three hypotheses are considered:

1) The load and impulse, generated during window jettison attempts will be significantly different between the dry and wet conditions as well as seat orientation
2) The load and impulse, applied to all four window strike locations during jettison attempts will be significantly different between the dry and wet conditions.
3) The load and impulse, generated during window jettison attempts will be significantly different between the two wet conditions.

1.3 Significance of Study

The findings will provide insight into how the strike load and impulse used to jettison the in-cabin push-out window influences the likelihood of performance success. It is hoped that the findings will inform Helicopter Underwater Egress trainers, regulators, and manufacturers in a way that will further improve the fidelity of future Helicopter Underwater Egress Training (HUET) programs.

2.0 Review of Literature

The following chapter will present a review of the literature associated with helicopter ditchings and force time curves. It includes a short description of Helicopter Underwater Egress Training (HUET), information on the push-out windows found in rotorcraft and details on how factors such as power and strike type influence load and impulse. In addition, the current requirements, which apply to emergency exits on rotorcraft are reported.

2.1 Helicopter Underwater Egress Training (HUET)

In Canada, all personnel who work on offshore installations must complete HUET. The training must be completed prior to their first departure and again every three years thereafter (Atlantic Canada Offshore Petroleum Training and Qualifications Committee, 2015). The training involves the performance of helicopter egress skills from a helicopter simulator (Section 3.1.2) at a recognized HUET provider. All of the underwater egress exercises are completed under the supervision of qualified HUET instructors. HUET provides instruction on how to properly jettison the in-cabin window (Section 2.2) and trainees are given the opportunity to attempt this exercise. As HUET exercises are not the main focus of this thesis, they will not be further discussed. For a detailed description of the exercises that must be completed during HUET, please refer to Taber, Dies, and Cheung (2011).

2.2 In-Cabin Push-Out Windows

The most frequently cited cause of death in a ditching event is drowning (Chen, Muller & Fogarty, 1993; Clifford, 1996; Glancy & Desjardins, 1971; Taber 2013). This suggests that passengers are failing to egress from the fuselage once it begins to submerge and capsize. The area of focus for this study was the push-out style in-cabin windows (Figure 2.1) on the Sikorsky S-92. There are several terms, which are used to describe these windows including: in-cabin exit, push-out window, in-cabin push-out window and escape window. For the remainder of this thesis, the term in-cabin push-out window will be used.

Figure 2.1: Simulated S-92 in-cabin push-out window.

While regulatory bodies such as the FAA, the CAA, and TC provide very specific regulations concerning the size and placement of emergency exits (Section 2.5), in-cabin push-out windows do not always fall under these regulations. If the window does not meet the minimum size necessary to be considered one of a Type *I-IV* emergency exit, (Section 2.5.1) it is considered a supplementary egress opening and is unregulated. While no concrete requirements exist concerning the push-out window, in Leaflet 44-30, the CAA does provide some general guidance on in-cabin push-out windows. The CAA suggests that the in-cabin window should have a minimum size of 17" by 14" (432 mm by 356 mm), which is large enough to fit the 95th percentile male. Also, opening of the in-cabin window should be "rapid and obvious" (CAA, 2006). It is important to note that no clarification of what might constitute an obvious opening mechanism or what amount of time is considered to be rapid is provided. As openings that are not large enough to be designated as emergency exits are optional, it is at the manufactures discretion whether they include these openings.

The Sikorsky S-92 is equipped with 10 in-cabin push-out windows (two in each row of passenger seating), which are not designated as emergency exits (Taber & Sweeney, 2014). During an optimal ditching situation, passengers will egress from the fuselage via designated emergency exits. However, since the in-cabin window is immediately to a passenger's left or right, they may attempt to jettison it to egress from the fuselage. While this choice seems obvious in an emergency situation, due to the fact that (on the Sikorsky S-92) the windows are unregulated, no publicly available data exists with regard to the forces necessary to jettison the window (Taber & Sweeney, 2014).

One study has focused on the forces necessary to jettison helicopter emergency exits (Swingle, 1995). Swingle (1995) examined designated emergency exit jettison forces for United States military helicopters reporting forces ranging from 10-45 pounds (4.5-20 kg) to operate the emergency exit handles. However, Swingle (1995) only provided quantitative data for mechanical exit jettison forces and did not consider the jettison forces for the push-out style windows.

A second study, Taber and Sweeney (2014) assessed the forces necessary to open a simulated in-cabin push-out window on a Modular Egress Training Simulator (METS^{TM}) using a purpose built force plate. The force plate was fitted into a window opening on the simulator and measured the force generated during jettison attempts using three load cells. The participants were tested in the normal (seat pan at 15 inches [38 cm]) and crash attenuated (seat pan at 7.9 inches [20 cm]) seat positions. Despite assurances that "a 5'9" (175.3 cm) female passenger with a mass of 110 lbs (49.9 kg) should be able to strike the window [on the actual aircraft] with enough force to jettison it clear of the frame" (Taber & Sweeney, 2014, p. 549), Taber and Sweeney (2014) found that over 50% of their participants were unable to generate enough maximal voluntary force to jettison the simulated exit in all seat positions. The mean maximal voluntary jettison forces produced by the participants ranged from 57 to 72 pounds (26-33 kg) depending on the location of force application on the surface of the exit (near or far corner or centre) and the seat height (normal or attenuated). Given the wide range of forces produced and the fact that the window was still not successfully jettisoned in some seating positions, the necessity of a clearly defined jettison force is obvious. Without a clearly defined and regulated in-cabin push-out window jettison force, a gap exists in the collective knowledge base of HUET program providers, helicopter operators, and individuals who may be required to open the in-cabin window in an emergency situation.

2.3 Force-Time Curves

The following section provides a basic overview of the characteristics of force-time curves as they pertain to this study and will refer extensively to Figure 2.2.

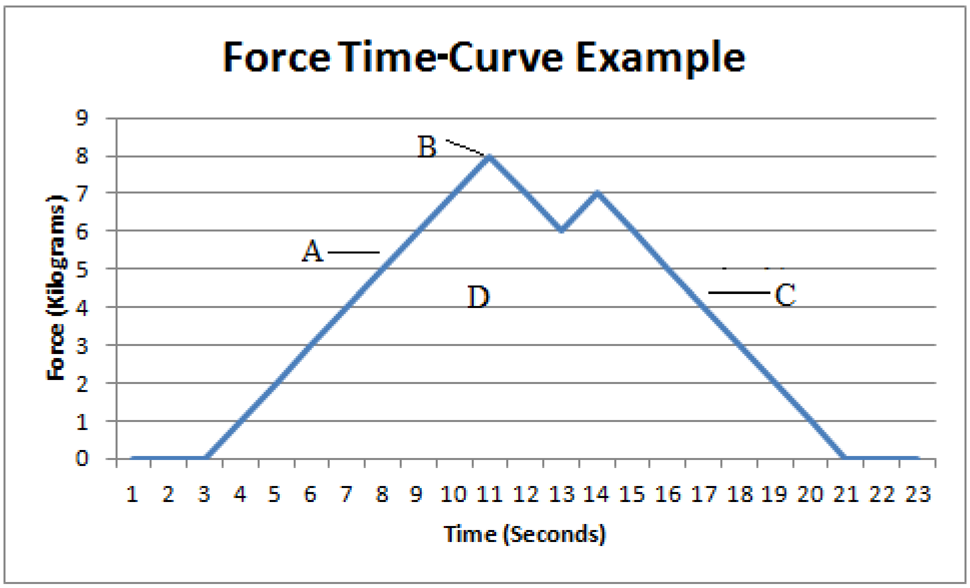

Figure 2.2: Force-Time Curve Example.

In reference to Figure 2.2, “A” refers to the force development phase. The force development phase is the “initial rapid rise in force” (Shechtman, Sindhu, & Davenport, 2007, p. 38) at the onset of a force-time curve. The rate of force development (RFD), can be calculated from the curve using the formula for the slope of a line:

$$\text{Slope (RFD)} = \frac{\text{RISE}}{\text{RUN}} = \frac{Y_2 - Y_1}{X_2 - X_1} = \frac{\text{Force}_2 - \text{Force}_1}{\text{Time}_2 - \text{Time}_1} \qquad (1)$$

In Figure 2.2, “B” refers to the peak force, which is the “highest value of force recorded” (Hakkinen et al., 1998). In this thesis, the term “load” will be used instead of peak force, as kilograms are the unit of measurement. “C” refers to the force decay phase defined as a “gradual decrease in force over time” (Shechtman et al., 2007, p. 38) after the peak force has been observed. The rate of force decay is calculated in the same manner as the RFD. “D” refers to the impulse. In a collision, impulse is equal to the change in momentum (Nakano, Iino, Imura & Kojima, 2014). On a force-time curve, impulse is the area under the curve and can be calculated using the integral function:

$$J = \int F\,dt \qquad (2)$$

Where: J = Impulse;

F= Force from $t1$ to $t2$

2.4 Factors that Influence Load and Impulse

As load and impulse are the two main factors, which were investigated for this study, it was necessary to discuss the factors which influence load and impulse. One of the most important factors which influence the ability of a person to generate a forceful strike is power (Chang et al., 2011). From a physics perspective, power is calculated by multiplying the force of a strike by the velocity of the strike (Chang et al., 2011):

$$P = FV, \tag{3}$$

Where: P = Power;

F = Force;

V = Velocity

From a martial arts perspective, Chang et al. (2011) state that "the total power [of the strike] depends mainly on the physical condition of an athlete, while the components/ power distributions…are influenced by technique applied, attacking location and posture at impact/contact." (p. 193). While Chang et al. (2011) focused specifically on martial arts applications, the concepts that they refer to apply to the in-cabin push-out window situation. The simulated window must be struck with sufficient power to knock it free from the roller latches which hold it in place (Section 3.1.2) and that power is directly related to the load that the participant applies to the push-out window through the formula P=FV where, for the purposes of this thesis, load is the surrogate measure of force.

Another factor that influences load magnitude and direction is the technique used to deliver the strike (Chang et al., 2011). Sorensen et al. (1996) state that most strikes occur in a "proximo-distal sequential order" (Sorensen et al., 1996, p. 483). Essentially, the proximal body segments accelerate first, followed by the distal body segments. When delivering a punch, the upper arm will accelerate first, while the fist striking the target (window in this thesis) will accelerate second (Sorensen et al., 1996).

Wasik (2011) writes that the velocity of the body segment, which must deliver the strike is, a key consideration for athletes attempting the break boards. This is logical as velocity represents the third variable in the equation P = FV. Hence, if an athlete is to generate a powerful strike, the strike will ideally have high force and a high velocity at the point of impact. While Wasik (2011) details the importance of force and velocity on the ability of a Tae Kwon Do athlete to break boards using a side kick, the core concepts are still applicable to the jettison task. These findings suggest that when using a high velocity strike to jettison the window, the power should be higher.

The range of motion of the body segments involved in the strike have been shown to influence the load and impulse that can be generated. While martial arts strikes such as the reverse punch rely on a large range of segment motion to generate impulse, Gulledge and Dapena (2008) write that some martial artists rely heavily on power punch techniques (strikes that begin less than 3 inches from the target). Gulledge and Dapena (2008) describe the mechanism of the technique as:

> During the impact of the power punch, the body transitions suddenly from a largely relaxed state to a fully ''tightened'' state, and then it returns to a relaxed state upon withdrawal of the fist. Advocates of the power punch contend that the sudden rigidity of the linkage between the fist and the rest of the body during impact promotes an improved transmission of force through the kinetic chain to the target, and thus results in a potent impact despite the presumed lower velocity of the fist in the power punch (p. 189).

Gulledge and Dapena (2007) found that while the power punch produced less peak force than the reverse punch, the impulse for both punches was similar as the force decay phase of the power punch was longer than the reverse punch. In a similar study, Nakano et al. (2014) found that the reduction of momentum of the punching arm produced 95% of the impulse on a target, leading to the conclusion that the most effective way to maximize impulse during a punch was to increase the speed (through the range of motion) of the punching arm.

Power, strike type, range of motion, and strike velocity are important considerations for martial artists as they are related to load and impulse that can be generated during a strike. While these factors are not specifically measured in this study, it is possible that they may influence the load and impulse generated during a jettison attempt due to the similarities in the tasks. While factors such as: muscle fibre typology, cortical representation, muscle volume, and type of instruction provided to participants (Sahaly, Vandewalle, Driss & Monod, 2001) have also been shown to influence power, speed, and impulse, they are beyond the scope of this thesis. While all of the research reviewed in this section has focused on martial arts practitioners, key similarities exist in the task of jettisoning the in-cabin push-out window. When breaking a board, the athlete must generate sufficient power, load, and impulse to overcome the tensile strength of the object. Similarly, to jettison the simulated window, a participant needed to generate sufficient power, load and impulse to compress the springs on the roller latches, which hold the force plate window in place.

2.5 Emergency Exit Types and Specifications

The following section presents the current regulations that an opening must conform if it is to be designated as an emergency exit on a rotorcraft. The regulations provided here are contained within the FAA's Federal Airworthiness Regulations (FAR). Regulatory bodies such as TC and the CAA have identical regulations as those provided here, thus the remainder of this section refers only to the FAA. While these regulations are prescriptive in nature, open to little interpretation, and regulate aspects including size of the exit or opening and placement of the exit or opening, it is important to note that they do not cover the in-cabin push-out windows if the window is of insufficient size.

2.5.1 Emergency Exit Types.

There are four types of emergency exits approved for use in a rotorcraft (FAR 29.807):

Type I: This type must be a rectangular opening of not less than 24 inches (610 mm) wide by 48 inches (1219 mm) high, with corner radii not greater than one-third the width of the exit, in the passenger area in the side of the fuselage at floor level and as far away as practicable from areas that might become potential fire hazards in a crash.

Type II: The same as type I, except the opening must be at least 20 inches (508 mm) wide by 44 inches (1118 mm) high.

Type III: The same as type I, except that

I. The opening must be at least 20 inches (508 mm) wide by 36 inches (914 mm) high and;

II. The exits need not be at floor level

Type IV: This type must have a rectangular opening of not less than 19 inches (483 mm) wide by 26 inches (660 mm) high, corner radii not greater than one-third the width of the exit, in the side of the fuselage with a step-up inside the rotorcraft of not more than 29 inches (737 mm).

2.5.2 Emergency Exit Placement.

In addition to governing the types of emergency exits approved for use on rotorcraft, the FAA also regulates the number of emergency exits, which must be present in a passenger cabin (FAR 29.807). The number of required exits is based on the number of passengers that the rotorcraft is capable of carrying. Table 2.1 outlines the number of emergency exits that must be present of each side of a rotorcraft fuselage.

Table 2.1: The number of each type of emergency exits necessary on each side of the fuselage of a rotorcraft (FAR 29.807).

Passenger Seating Capacity	*Type I*	*Type II*	*Type III*	*Type IV*
1-10				1
11-19			1 or	2
20-39		1		1
40-59	1			1
60-79	1		1 or	2

Also, if a rotorcraft is certified for ditching it must conform to additional regulations concerning exit placement. These regulations are based on the number of passengers the craft is capable of carrying. For a rotorcraft with passenger capacity of nine or less, one exit meeting *type III* guidelines or larger must sit above the waterline on each side of the fuselage. For those rotorcraft with a capacity of ten or more, one *type III* exit must sit above the waterline on each side of the fuselage for each unit of thirty-five passenger seats. Additionally, for those with passenger capacities of ten or more, not less than two *type III* exits must sit above the waterline on each side of the fuselage (FAR 29.807).

2.5.3 Emergency Exit Performance.

In addition to regulating the size and placement of a designated emergency exit, the FAA has several other regulations concerning aspects such as crashworthiness of the exit, latch types and general emergency protocols. However, when compared to the regulations concerning exit types and placement, these regulations are more ambiguous and may be satisfied through several different means.

From FAR 29.809, each emergency exit must:

a) Consist of a moveable door or hatch in the external walls of the fuselage and must provide an unobstructed opening to the outside.
b) Be openable from the inside and from the outside.
c) The means of opening each emergency exit must be simple and obvious and may not require exceptional effort.
d) There must be a means for locking each emergency exit and for preventing opening in flight inadvertently or as a result of mechanical failure.
e) There must be means to minimize the probability of the jamming of any emergency exit in a minor crash landing as a result of fuselage deformation.

Given the ambiguity of these regulations, it is not unreasonable to assume that different manufacturers of rotorcraft may use different mechanisms and openings to satisfy these regulations. In fact, the vast number of mechanisms for exit operation was the focus of a study conducted by Brooks and Bohemier (1997). In this study, the authors examined 27 emergency windows and hatches to highlight the fact that there is no standardization across helicopter types and that individuals may need to learn/memorize the proper operation of different mechanisms in case of an emergency. For example, among these 27 emergency exits, Brooks and Bohemier (1997) found nine different mechanisms for operation including several different levers and the push-out type mechanism. Despite the fact that all the exits conformed to the FAA's regulations, Brooks and Bohemier (1997) concluded that in an emergency situation, it was likely that the vast number of mechanisms would cause confusion to passengers and flight crew who were already likely panicked by their ordeal. The results of this study seem to suggest that standardization of exit operation across the industry should be a future consideration for helicopter manufacturers.

3.0 Methodology

A secondary data set for a project entitled “Human Factors Examination of Underwater Egress Forces Required to Open an S92 Push-out Exit” was provided by Falck Safety Services Canada (FSSC) to be used in this study. Ethics clearance for the original research project was granted by the Health Research Ethics Authority (HREA). Throughout the data collection, the Principal Investigator from FSSC was assisted by other FSSC staff and are referred to as “the researchers” in this thesis.

3.1 Equipment

Several specialized pieces of equipment were developed and utilized for the data collection.

3.1.1 METS^{TM} Push-Out Force Plate (PFP).

To measure the maximal voluntary push-out load that the participant’s generated at various locations on the window (See Section 3.3 for details on the testing protocol), a platform scale assembly push-out force plate (PFP) was used. The force plate was purpose-built for FSSC and was previously used by Taber and Sweeney (2014).

The PFP measured 18” (457 mm) by 21.25” (540 mm) and was comprised of four individual layers, three of which were custom machined out of lexan (Figure 3.1):

1) Load Cell Mounting Layer (Lexan 1). This layer was machined from lexan and was designed to match the outside dimensions of the simulated S92 in-cabin window. It contained a 1.00” x 3.15” (25mm x 80 mm) rectangular hole, which had been machined in the middle for the load cell cables to pass through.

2) METS^{TM} modified push-out frame. This layer features the grooves, which the roller latches sit in when the simulated window is placed in the METS^{TM}.

3) Modified METS^{TM} S92 push-out pane (Lexan 2). This layer functions as the actual pushing surface on a standard simulated window. For the purposes of the study, an additional layer of lexan was added (4) to function as the push surface.

4) Force Application Panel (Lexan 3). This layer was custom machined from lexan and functioned as the surface which the participants applied the load while attempting to jettison the PFP.

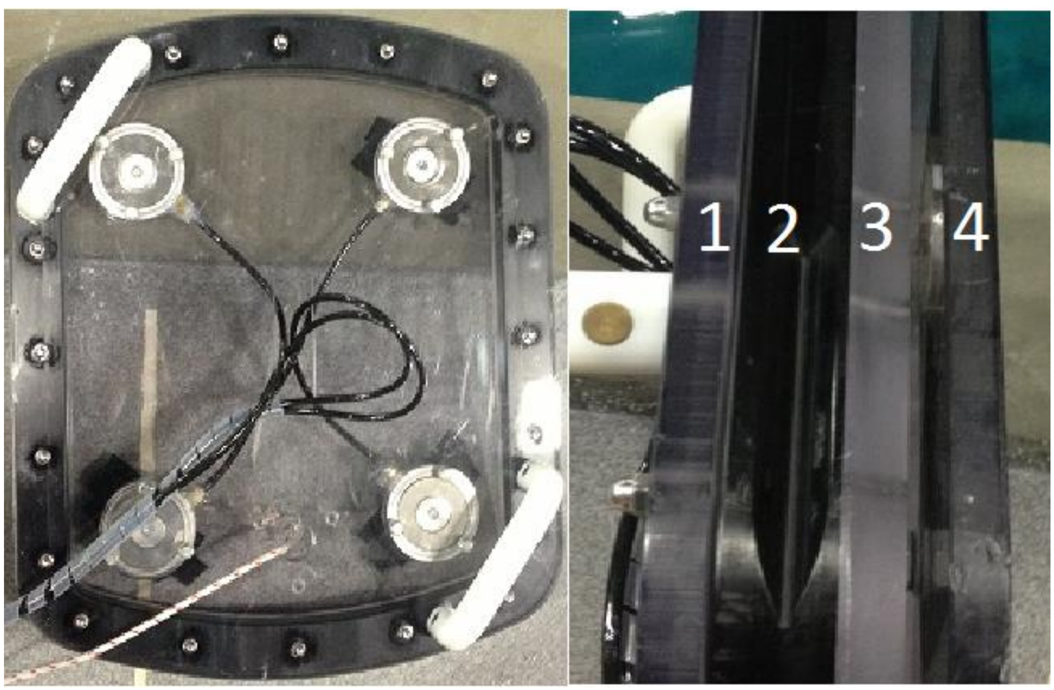

Figure 3.1: METS^{TM} Push-Out Force Plate (PFP).

The PFP measured the maximal voluntary push-out load using four ring load cells (RLC) (Model RLC, 250 kg capacity Vishay-Revere Transducers, Malvern, PA, USA). These load cells were mounted to lexan 1 in a square pattern with one load cell in each corner. Each load cell cable was waterproof and measured 75 feet (22.7 m) long and was connected to a National Instruments 4 cell junction box (NI 9237, 9171 Chassis, National Instruments). The junction box combined the four load cell signals into a single output that could be monitored in real time on a computer running LabVIEW. The load cell data were collected at a frequency of 1000 Hz. For testing, the PFP was placed into the in-cabin window opening on the METS™ (Figure 3.3) and the participants attempted to jettison it using different strike types and strike points (See Section 3.3 for details on strike types and points). The PFP measured, in kilograms, the load produced by each participant during their attempts to jettison the PFP.

3.1.2 Modular Egress Training Simulator (METS™).

The METS™ Model 50B (Figure 3.2) is the latest model to be produced and has been designed to match the largest transport helicopters available such as the Sikorsky S-92. The seats have been designed so that they are able to sit at both the normal (15" [38 cm]) and attenuated (stroked) (7.9" [20 cm]) height. Additionally, the seats can be moved so that the seating configuration of the METS™ can be adjusted to match that of several different helicopters. The emergency exits dimensions on the METS™ typically match those found on the Sikorsky S-92 to within 1/8" (3.2mm) (Taber & Sweeney, 2014). The push-out style in-cabin windows are held in place by six roller latches (Figure 3.4) that compress when load is applied to the window, allowing it to be jettisoned from the frame. The loads required to compress these latches can be adjusted by increasing or decreasing the tension on the springs contained within the roller latch. The in-cabin windows have been designed to respond in a similar manner to those found on the rotorcraft, however, it is unknown if the load required to jettison the simulated window accurately represents the force necessary to jettison an actual window.

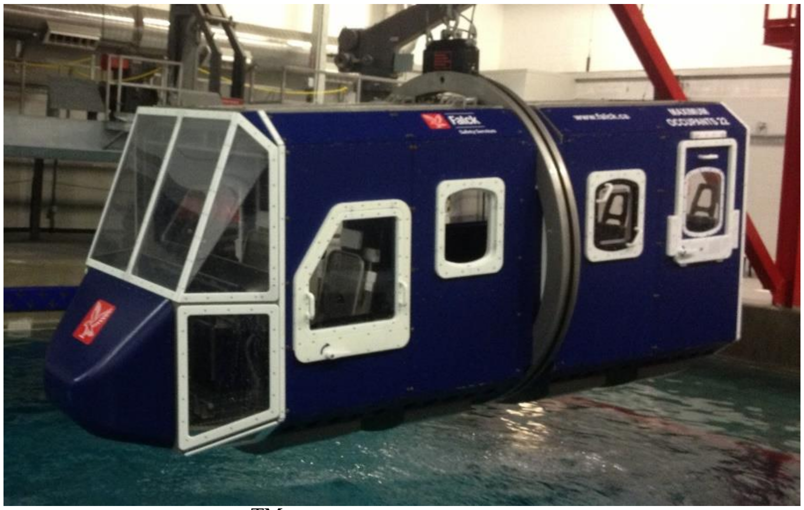

Figure 3.2: METS^{TM} Model 50B used for the data collection.

Figure 3.3: METS^{TM} Model 50B PFP testing set-up.

Figure 3.4: A roller latch from a METS^{TM} Model 50B.

3.2 Participants

FSSC's study (Taber, 2016) used a convenience sampling technique to recruit participants who completed two data collection sessions. This study was provided with the data from 40 participants for data analysis (Section 4.0). Participants were recruited from those completing safety training at FSSC, through a recruitment poster on the FSSC website and through word of mouth. Standard HREA informed consent procedures were carried out. Participants were free to withdraw from the study at any time for any reason with no penalty and alphanumeric codes were used to ensure their anonymity.

3.3 Data Collection Sessions

The study consisted of two data collection sessions. The first session was in the METS^{TM} on the pool deck (Referred to as "Dry" for the remainder of the thesis) and the second session was in the METS^{TM} underwater (Referred to as "Wet" for the remainder of the thesis. The reason for doing the dry session first for every participant was to provide an opportunity for participants to practice opening the exit in a dry controlled environment. Participants were not asked to attempt a trial in the wet condition if they were unsuccessful for that trial in the dry condition.

3.3.1 Dry Testing.

The dry data collection session consisted of 29 different trials and considered three different variables: seat position, strike location, and strike type. There were three different seating orientations and seat pan heights. These were: window seat with seat pan at normal (15" [38 cm]) height, window seat with seat pan at stroked (7.9" [20 cm]) height and aisle seat with seat pan at normal (15" [38 cm]) height. There were four different strike locations on the PFP that participants were instructed to strike. These were: lower near corner (right), lower far corner (left), upper near corner (right), and upper far (left) corner. Finally, there were three different strike types that participants were instructed to use. The first strike type was a static hand push. For this strike type, participants had to place their right hand on the PFP surface and attempt to push the window open. The hand had to remain in contact with the PFP throughout the push. The push had to be entirely static; it could not contain a dynamic action to initiate it. The second strike type was a dynamic hand strike. For this, participants attempted to jettison the window using a punch type motion. They were permitted to hit the window in any hand position they preferred including with the side of their fist and the knuckles. The final strike type was a dynamic elbow strike. For this strike type, participants were instructed to cup the right fist within the left hand so both arms acted in unison. They were then instructed to quickly strike the window with their right elbow by contracting the right posterior deltoid and the left triceps brachii in unison.

These trials were divided into three different protocols based on seating position. For each trial, the participant was given a maximum of three attempts to jettison the window and the jettison attempt that produced the highest load output was chosen for analysis. The descriptions of these trials can be found below in Tables 3.1-3.3.

Table 3.1: Trials for the window seat with seat pan at 15" (38 cm) (Normal).

Trial Number	Strike Type	Strike Location
1	Static Hand Push	Lower Near Corner
2	Static Hand Push	Lower Far Corner
3	Static Hand Push	Upper Near Corner
4	Static Hand Push	Upper Far Corner
5	Dynamic Elbow Strike	Lower Near Corner
6	Dynamic Elbow Strike	Lower Far Corner
7	Dynamic Elbow Strike	Upper Near Corner
8	Dynamic Hand Strike	Lower Near Corner
9	Dynamic Hand Strike	Lower Far Corner
10	Dynamic Hand Strike	Upper Near Corner
11	Dynamic Hand Strike	Upper Far Corner

Table 3.2: Trials for the window seat with seat pan at 7.9" (20 cm) (Stroked).

Trial Number	Strike Type	Strike Location
1	Static Hand Push	Lower Near Corner
2	Static Hand Push	Lower Far Corner
3	Static Hand Push	Upper Near Corner
4	Static Hand Push	Upper Far Corner
5	Dynamic Elbow Strike	Lower Near Corner
6	Dynamic Elbow Strike	Lower Far Corner
7	Dynamic Hand Strike	Lower Near Corner
8	Dynamic Hand Strike	Lower Far Corner
9	Dynamic Hand Strike	Upper Near Corner
10	Dynamic Hand Strike	Upper Far Corner

Table 3.3: Trials for the Aisle seat with seat pan at 15” (38 cm) (Normal).

Trial Number	Strike Type	Strike Location
1	Static Hand Push	Lower Near Corner
2	Static Hand Push	Lower Far Corner
3	Static Hand Push	Upper Near Corner
4	Static Hand Push	Upper Far Corner
5	Dynamic Hand Strike	Lower Near Corner
6	Dynamic Hand Strike	Lower Far Corner
7	Dynamic Hand Strike	Upper Near Corner
8	Dynamic Hand Strike	Upper Far Corner

3.3.2 Wet Testing.

Prior to beginning the wet testing sessions, researchers used each participant's dry condition performance to develop an individualized wet testing matrix. The number of trials the participant completed in the wet condition was dependent on both the number of successful trials during the participant's dry sessions and the researcher's expectation for their success at a particular trial based on the dry trial data. Given the dynamic nature of underwater egress, one wet trial was selected for each of the possible strike/seat positions as opposed to a full repeated measures for all positions. This process ensured that participants were not asked to complete a total of 58 underwater egresses. Therefore, wet testing consisted of six trials, which reflected the trials with the lowest rates of failure during dry testing. The trials with the lowest failure rate were selected to ensure that participants were able to succeed in at least some of the wet trials.

The wet testing sessions also considered an additional variable, the rotation of the METS™ with each trial completed twice, once with the METS™ completely inverted (180º) and once with the METS™ partially inverted (~120º). Thus, the maximum number of trials a participant could complete was 12. It is important to note that each wet testing trial required the participant to be fully submerged for approximately 10 seconds, thus if during one of the trials the participant could not successfully jettison the window after three attempts then a HUET instructor would complete the jettison for them. A list of the wet testing trials can be found in Table 3.4.

Table 3.4: Wet Testing Trials.

Trial Number	Seating Position	Strike Type	Strike Point	Angle
1	Normal	Dynamic Elbow	Lower Far	180º
2	Normal	Dynamic Hand	Upper Far	180º
3	Stroke	Dynamic Elbow	Lower Near	180º
4	Stroke	Dynamic Hand	Upper Near	180º
5	Aisle	Static Hand	Lower Near	180º
6	Aisle	Dynamic Hand	Lower Near	180º
7	Normal	Dynamic Elbow	Lower Far	120º
8	Normal	Dynamic Hand	Upper Far	120º
9	Stroke	Dynamic Elbow	Lower Near	120º
10	Stroke	Dynamic Hand	Upper Near	120º
11	Aisle	Static Hand	Lower Near	120º
12	Aisle	Dynamic Hand	Lower Near	120º

3.4 Statistical Analysis

As each participant was given up to three attempts to jettison the simulated window for each trial, the attempt that had the highest recorded peak load was chosen for analysis. The loads and impulses were determined for each of the trials using Microsoft Excel 2013. The load for a trial was calculated by taking the maximum value attained during the trial. The trapezoid rule was used (Pidgeon, 1996) to calculate impulse by first identifying the start and finish of the trial and then using the following formula:

$$(B_{(X)} + B_{(X+1)})/2*(A_{(X+1)} - A_{(X)}) \quad (1)$$

Where: A numbered 1 to 6000, a possible 6 seconds of load data;

B = Load in kg

X = The Microsoft Excel cell which was used, for example, Cell B1, Cell A1321

This time series was summated and since these data were sampled at 1000 Hz, the total was divided by 1000 to allow for the expression of the impulse in kg*s.

Once the load and impulse were calculated for each trial, the data were analyzed using IBM Statistics SPSS (v20). Prior to beginning the statistical analyses, the data for each trial was individually checked for normality using the Kolmogorov-Smirnov test and the presence of outliers by visually inspecting relevant boxplots. Once this was completed, 12 (Six trials for two variables) repeated measures analyses of variance (or Friedman's ANOVA) were used to determine if significant differences existed in load and impulse between the dry, wet 180º and wet 120º conditions. When the ANOVA (or Freidman's test) result was significant, post hoc testing using a Bonferroni adjusted alpha level was conducted to examine the strength of the differences. For this, the dependent *t*-test (or Wilcoxon's Signed Rank Test) was used.

4.0 Results

The following chapter presents the results of the statistical analyses detailed in Section 3.4. Found below is a general summary of the statistical analyses. The first section of this chapter presents the results of the statistical analyses for the load data while the second section presents the results of the analyses for the impulse data.

Table 4.1: The number of participants and failure rate for each trial.

Number	Trial (Seat, Location and Strike Type)	Number of Participants (Dry)	Failure Rate, Dry (%)	Number of Participants (180º)	Failure Rate (180º)	Number of Participants (120º)	Failure Rate (120º)
1	Normal, Lower Near, Static Hand	40	95%	–	–	–	–
2	Normal, Lower Far, Static Hand	40	97.5%	–	–	–	–
3	Normal, Upper Near, Static Hand	40	82.5%	–	–	–	–
4	Normal, Upper Far, Static Hand	40	85%	–	–	–	–
5	Normal, Lower Near, Dynamic Elbow	40	5%	–	–	–	–
6	Normal, Lower Far, Dynamic Elbow	40	12.5%	33	18%	32	12.5%
7	Normal, Upper Near, Dynamic Elbow	40	42.5%	–	–	–	–
8	Normal, Lower Near, Dynamic Hand	40	97.5%	–	–	–	–
9	Normal, Lower Far, Dynamic Hand	40	37.5%	–	–	–	–
10	Normal, Upper Near, Dynamic Hand	40	47.5%	–	–	–	–
11	Normal, Upper Far, Dynamic Hand	40	20%	31	100%	30	100%
12	Stroke, Lower Near, Static Hand	40	80%	–	–	–	–
13	Stroke, Lower Far, Static Hand	40	90%	–	–	–	–
14	Stroke, Upper Near, Static Hand	40	90%	–	–	–	–
15	Stroke, Upper Far, Static Hand	40	90%	–	–	–	–
16	Stroke, Lower Near, Dynamic Elbow	38	37%	27	7%	25	0%
17	Stroke, Lower Far, Dynamic Elbow	35	31%	–	–	–	–
18	Stroke, Lower Near, Dynamic Hand	40	90%	–	–	–	–
19	Stroke, Lower Far, Dynamic Hand	40	40%	–	–	–	–
20	Stroke, Upper Near, Dynamic Hand	40	27.5%	28	100%	27	100%
21	Stroke, Upper Far, Dynamic Hand	40	30%	–	–	–	–
22	Aisle, Lower Near, Static Hand	40	2.5%	39	13%	37	8%
23	Aisle, Lower Far, Static Hand	40	37.5%	–	–	–	–
24	Aisle, Upper Near, Static Hand	40	37.5%	–	–	–	–
25	Aisle, Upper Far, Static Hand	39	74%	–	–	–	–
26	Aisle, Lower Near, Dynamic Hand	40	12.5%	33	3%	32	3%
27	Aisle, Lower Far, Dynamic Hand	40	47.5%	–	–	–	–
28	Aisle, Upper Near, Dynamic Hand	40	57.5%	–	–	–	–
29	Aisle, Upper Far, Dynamic Hand	39	87%	–	–	–	–

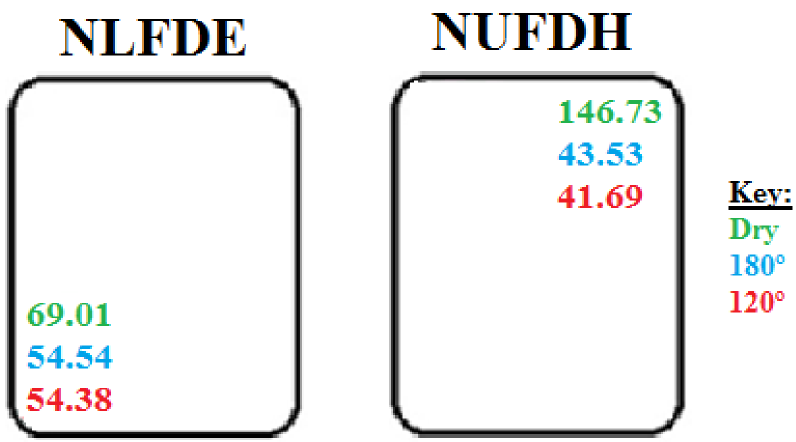

Figure 4.1: Mean loads (kg) for the normal seat strikes in the three conditions.

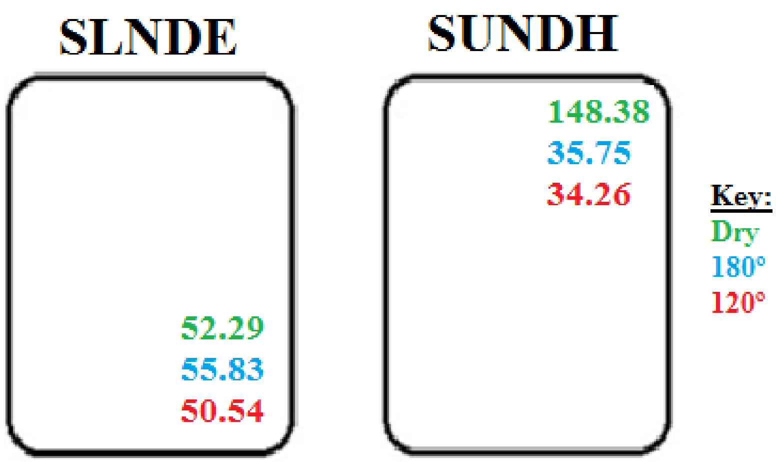

Figure 4.2: Mean loads (kg) for the stroke seat strikes in the three conditions.

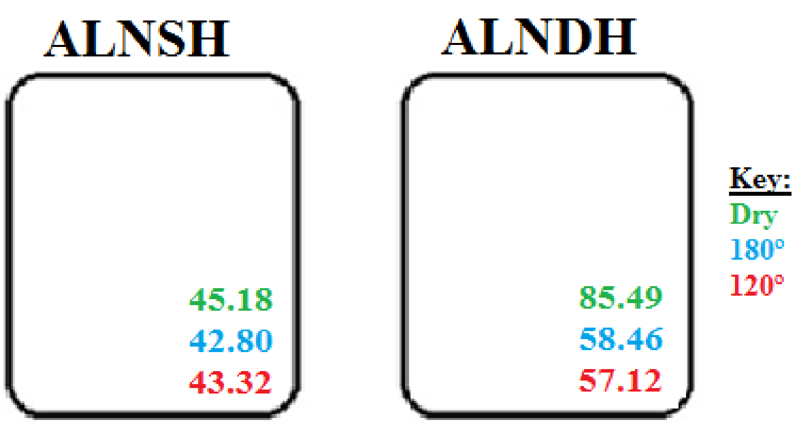

Figure 4.3: Mean loads (kg) for the aisle seat strikes in the three conditions.

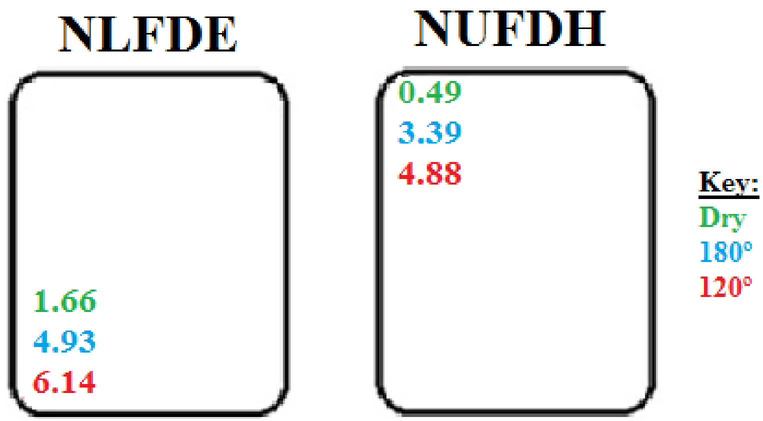

Figure 4.4: Mean impulse (kg*s) for the normal seat strikes in the three conditions.

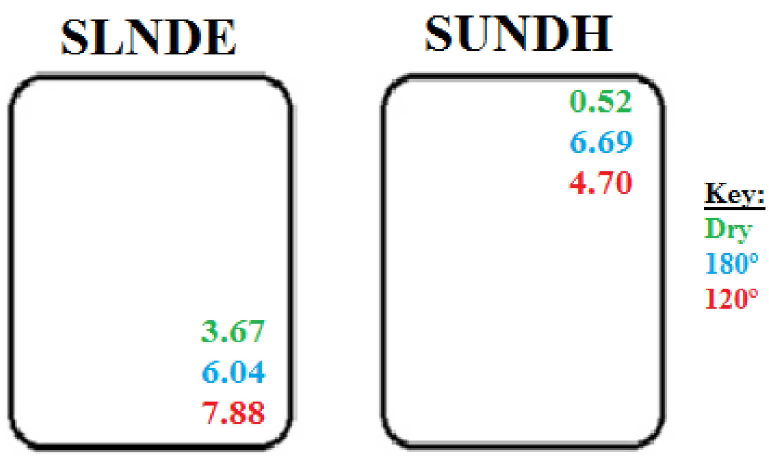

Figure 4.5: Mean impulse (kg*s) for the stroke seat strikes in the three conditions.

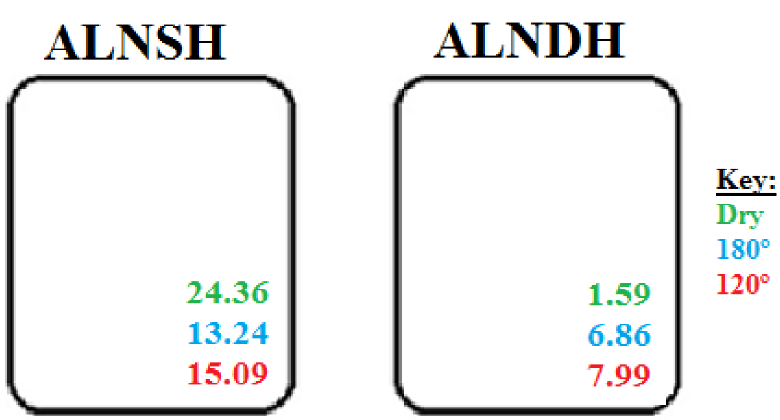

Figure 4.6: Mean impulse (kg*s) for the aisle seat strikes in the three conditions.

4.1 Load for the Dry and Wet Conditions

4.1.1 Normal, Lower Far, Dynamic Elbow.

According to the Kolmogorov-Smirnov test load in the dry, 180º, and 120º condition were all normally distributed. Box plots were visually examined to check for outliers with at least one outlier detected for each of the three conditions. While removing the outlier would enable the use of the repeated measures ANOVA, Field (2009) recommends against the removal of an outlier unless it can be guaranteed that the outlier is not part of the population. As the presence of an outlier violates one of the assumptions of the parametric repeated measures ANOVA, Friedman's ANOVA was used to examine the data (Field, 2009). The results of Friedman's ANOVA indicated that the load was significantly different between the three conditions. To explore the specific differences between conditions, Wilcoxon's Signed Rank Test was used with Bonferroni adjusted alpha levels of $p = .017$. As seen in Figure 4.7, load was significantly higher in the dry condition than it was in the wet 120º rotation condition. However, there was no significant difference between the dry condition and the wet 180º rotation condition, or the wet 180º condition and the wet 120º condition (load data can be found in Table 4.2).

Table 4.2: Descriptive statistics for load, NLFDE.

Condition	Analysis	Kolmogorov-Smirnov Test Statistic	Mean (kg)	Standard Deviation	Standard Error	Test Statistic
Dry	_	D_{29} = .100, p = .200	69.01	12.67	2.35	-
Wet 180º	_	D_{29} = .127, p = .200	59.54	18.12	3.36	-
Wet 120º	_	D_{29} = .101, p = .200	54.38	14.96	2.78	-
-	Freidman's ANOVA	-	-	-	-	$\chi^2_F(2) = 9.17$, p = .01*
-	Dry*180	-	-	-	-	z = -1.83, p = .067, r = -.23
-	Dry*120	-	-	-	-	z = -3.41, p = .001*, r = -.44
-	180*120	-	-	-	-	z = -1.47, p = .141, r = -.19

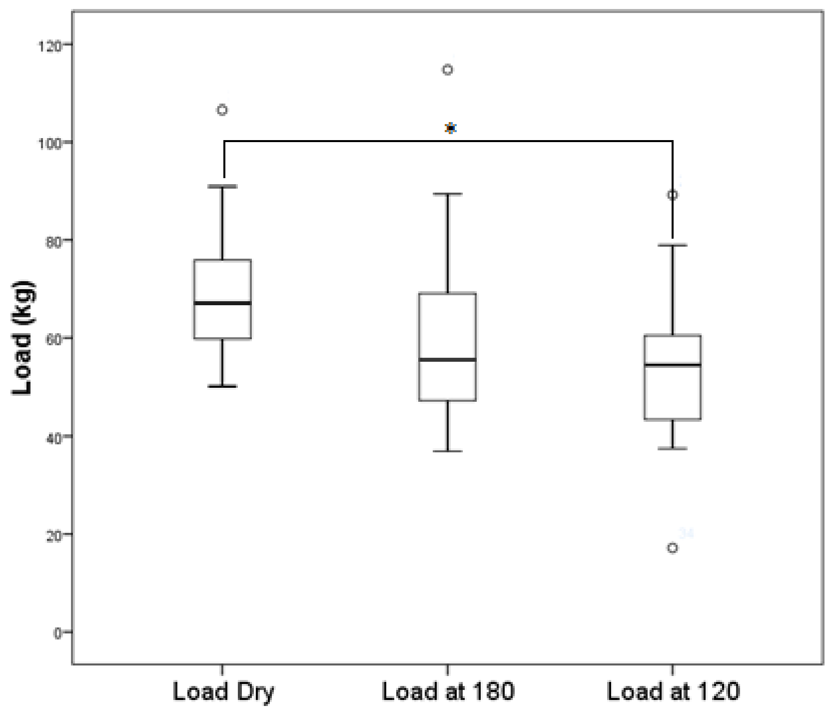

Figure 4.7: Comparison of load generated across the three test conditions when using the NLFDE.

4.1.2 Normal Upper Far Dynamic Hand.

Before beginning this analysis, the data for one participant was removed as the test results suggested that the person incorrectly struck the window during both the wet 180º and wet 120º rotation conditions. Load in the dry, 180º, and 120º rotation condition were all normally distributed. After visually examining the relevant boxplots, it was concluded that no outliers existed in the data. As its assumptions were not violated, a repeated measures ANOVA was used to examine the data (Field, 2009). Mauchly's test indicated that the assumption of sphericity was violated ($\chi^2(2) = 20.326$, $p < .001$), therefore degrees of freedom were adjusted using the Greenhouse-Geisser estimates of sphericity ($\varepsilon = .65$) as both estimates of sphericity were less than 0.75 (Field, 2009). The results indicated that a significant difference existed in load between the three conditions. To examine specific differences between the individual conditions, dependent *t*-tests were conducted with Bonferroni adjusted alpha levels of $p = .017$. As seen in Figure 4.8, load in the dry condition was significantly greater than load in the wet 180º rotation condition and the wet 120º rotation condition. There was no significant difference in load between the wet 180º and 120º conditions (load data can be found in Table 4.3).

Table 4.3: Descriptive statistics for load, NUFDH.

Condition	Analysis	Kolmogorov-Smirnov Test Statistic	Mean (kg)	Standard Deviation	Standard Error	Test Statistic
Dry	-	$D_{29} = .115$, $p = .200$	146.73	29.57	5.49	-
Wet 180º	-	$D_{29} = .129$, $p = .200$	43.53	13.76	2.56	-
Wet 120º	-	$D_{29} = .132$, $p = .200$	41.69	12.24	2.27	-
-	RM ANOVA	-	-	-	-	$F_{(1.31, 36.63)} = 302.02$, $p < .001$*
-	Dry*180	-	-	-	-	$t_{(29)} = 18.30$, $p < .001$, $r = .96$*
-	Dry*120	-	-	-	-	$t_{(28)} = 18.80$, $p < .001$, $r = .96$*
-	180*120	-	-	-	-	$t_{(29)} = .85$, $p = .404$, $r = .16$

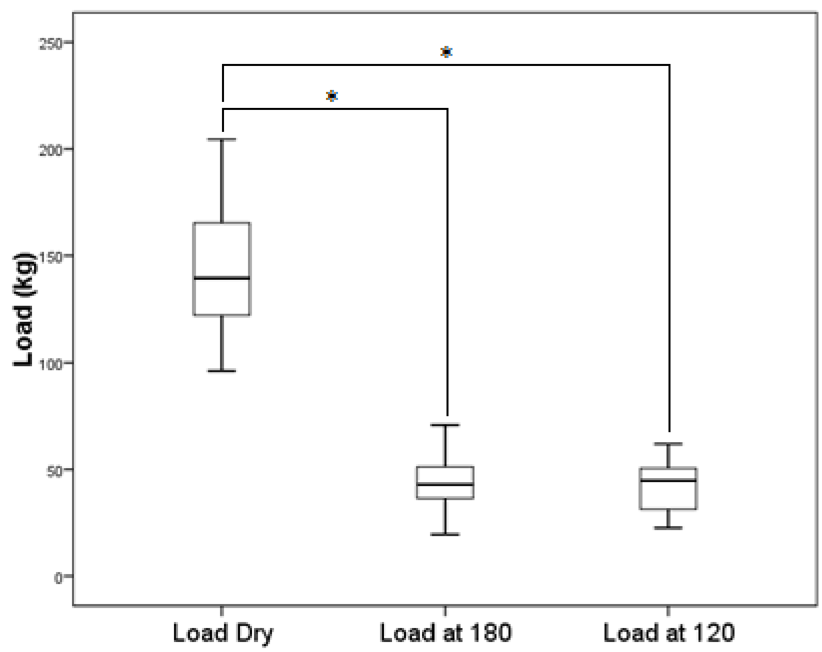

Figure 4.8: Comparison of load generated across the three test conditions when using the NUFDH.

4.1.3 Stroke Lower Near Dynamic Elbow.

Load in the dry condition was normally distributed while load in the wet 180º and 120º rotation conditions were not. After visually examining the relevant boxplots, several outliers were detected in both the wet 180˚ and wet 120˚ rotation conditions. The results of Freidman's ANOVA indicated that no significant difference existed between load in the dry, wet 180º and wet 120º conditions. As the results from the ANOVA were non-significant, no post-hoc testing was conducted (load data can be found in Table 4.4).

Table 4.4: Descriptive statistics for load, NLNDE.

Condition	Analysis	Kolmogorov-Smirnov Test Statistic	Mean (kg)	Standard Deviation	Standard Error	Test Statistic
Dry	-	$D_{(25)} = .127$, $p = .200$	52.29	12.29	2.46	-
Wet 180	-	$D_{(25)} = .202$, $p = .010$*	55.83	21.21	4.24	-
Wet 120	-	$D_{(25)} = .335$, $p < .001$*	50.54	16.51	3.30	-
-	Freidman's ANOVA	-	-	-	-	$\chi^2_F(2) = 2.61$, $p = .284$

4.1.4 Stroke Upper Near Dynamic Hand.

Load in the dry condition and the wet 120º rotation condition were normally distributed while load in the 180º rotation condition was not. To determine if outliers were present in the data set, boxplots were visually examined. This revealed that outliers existed for both the wet 180º and wet 120º rotation conditions. The results of Freidman's ANOVA indicated that a significant difference existed between load in the dry, wet 180º and wet 120º conditions. To examine the strength of the differences a Wilcoxon Signed Rank Test was used with Bonferroni adjusted alpha levels of $p = .017$. As seen in Figure 4.9, load was significantly greater in the dry condition than in the wet 180º condition and the wet 120º rotation condition. There was no significant difference in load between the wet 180º and 120º conditions (load data can be found in Table 4.5).

Table 4.5: Descriptive statistics for load, SUNDH.

Condition	Analysis	Kolmogorov-Smirnov Test Statistic	Mean (kg)	Standard Deviation	Standard Error	Test Statistic
Dry	-	$D_{(24)} = .159$, $p = .119$	148.38	23.89	4.88	-
Wet 180º	-	$D_{(24)} = .240$, $p = .001$*	35.75	19.19	3.92	-
Wet 120º	-	$D_{(24)} = .155$, $p = .143$	34.26	11.74	2.39	-
-	Freidman's ANOVA	-	-	-	-	$\chi^2_F(2) = 37.68$, $p < .001$*
-	Dry*180	-	-	-	-	$z = -4.54$, $p < .001$*, $r = -.62$
-	Dry*120	-	-	-	-	$z = -4.37$, $p < .001$*, $r = -.62$
-	180*120	-	-	-	-	$z = -0.094$, $p = .937$, $r = -.01$

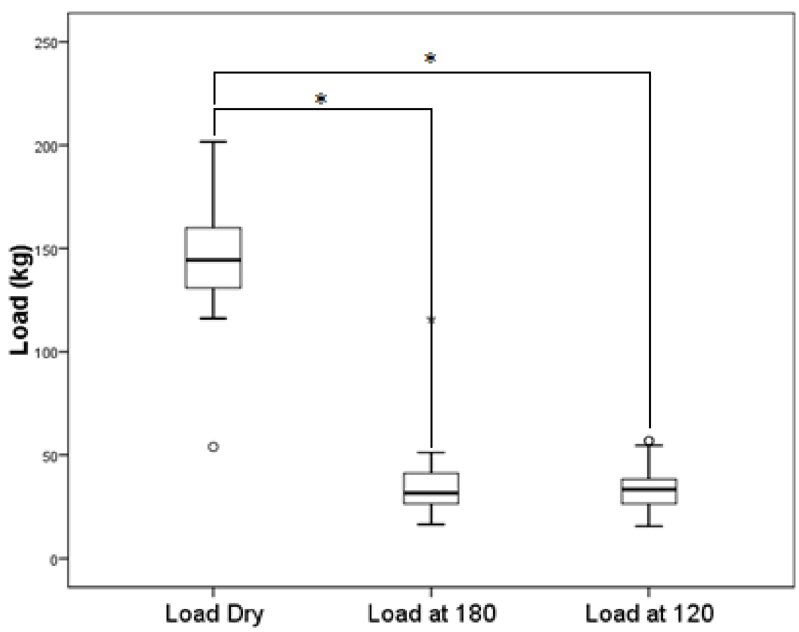

Figure 4.9: Comparison of load generated across the three test conditions when using the SUNDH.

4.1.5 Aisle Lower Near Static Hand.

Load in the dry condition was normally distributed while both load in the wet 180º and wet 120º rotation conditions were not. To check for outliers, the relevant boxplots were considered with outliers detected for all three conditions. The results of Freidman's ANOVA indicated that there was no significant difference between load in the dry, wet 180º and wet 120º conditions. As the ANOVA was non-significant, no post-hoc testing was conducted (load data can be found in Table 4.6).

Table 4.6: Descriptive statistics for load, ALNSH.

Condition	Analysis	Kolmogorov-Smirnov Test Statistic	Mean (kg)	Standard Deviation	Standard Error	Test Statistic
Dry	-	$D_{(34)} = 0.114$, $p = .200$	45.18	2.98	0.51	-
Wet 180º	-	$D_{(34)} = 0.204$, $p = .001$*	42.80	6.56	1.12	-
Wet 120º	-	$D_{(34)} = 0.172$, $p = .012$*	43.32	7.55	1.30	-
-	Freidman's ANOVA	-	-	-	-	$\chi^2_F(2) = 5.20$, $p = .084$

4.1.6 Aisle Lower Near Dynamic Hand.

Load in the dry condition, the wet 180º and the wet 120º condition were all normally distributed. After visually examining the relevant boxplots, it was concluded that no outliers were present for either condition. Mauchly's test indicated that the assumption of sphericity was violated ($\chi^2(2) = 12.56$, $p = .002$), therefore degrees of freedom were adjusted using the Huynh-Feldt estimates of sphericity ($\varepsilon = .77$) as one of the estimates of sphericity was greater than 0.75 (Field, 2009). The results indicated that a significant difference existed in load between the three conditions. To examine the strength of the differences between the individual conditions, a dependent *t*-test was conducted with

Bonferroni adjusted alpha levels of p = .017. As seen in Figure 4.10, load in the dry condition was significantly greater than load in the wet 180º rotation condition and the wet 120º rotation condition. There was no significant difference in load between the wet 180º and wet 120º rotation conditions (load data can be found in Table 4.7).

Table 4.7: Descriptive statistics for load, ALNDH.

Condition	Analysis	Kolmogorov-Smirnov Test Statistic	Mean (kg)	Standard Deviation	Standard Error	Test Statistic
Dry	-	$D_{(31)}$ = 0.093, p = .200	85.49	26.31	4.73	-
Wet 180º	-	$D_{(31)}$ = 0.114, p = .200	58.46	16.22	2.91	-
Wet 120º	-	$D_{(31)}$ = 0.115, p = .200	57.12	13.31	2.40	-
-	RM ANOVA	-	-	-	-	$F_{(1.54, 46.15)}$ = 26.16, p < .001*
-	Dry*180	-	-	-	-	$t_{(31)}$ = 5.72, p < .001*, r = .72
-	Dry*120	-	-	-	-	$t_{(31)}$ = 5.75, p < .001*, r = .72
-	180*120	-	-	-	-	$t_{(30)}$ = 0.47, p = .639, r = .09

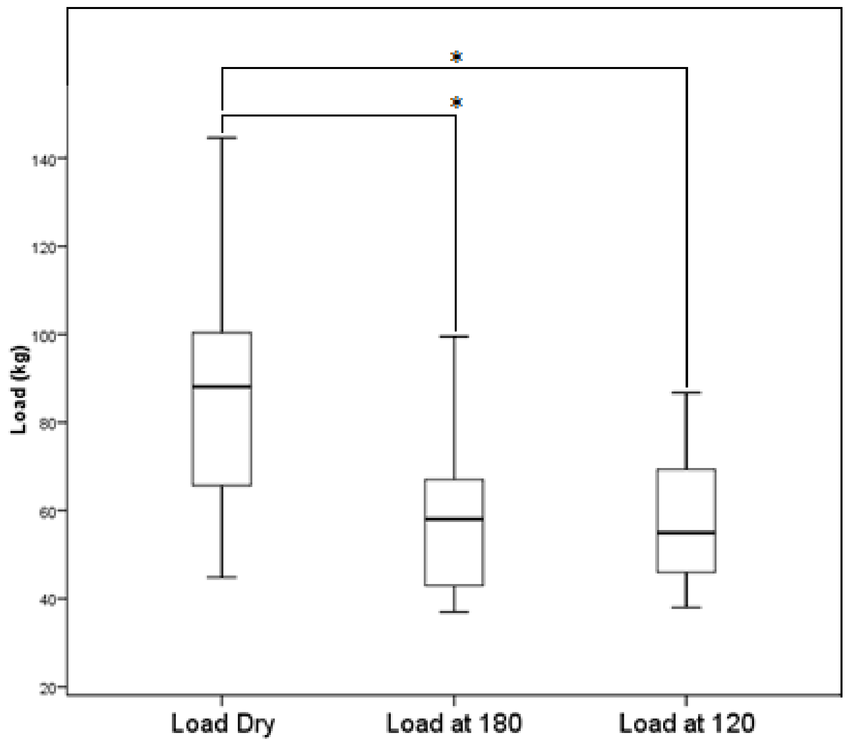

Figure 4.10: Comparison of load generated across the three test conditions when using the ALNDH.

4.2 Impulse for the Dry and Wet Conditions

4.2.1 Normal Lower Far Dynamic Elbow.

Impulse in the dry condition was normally distributed, however, impulse in the wet 180^o condition and the wet 120^o condition were not. In addition, an examination of boxplots indicated that one outlier was present for both wet conditions. The results of Freidman's ANOVA indicated that a significant difference existed between impulse in the dry, wet 180^o and wet 120^o conditions. To explore the strength of the differences, a Wilcoxon Signed Rank Test was used with a Bonferroni adjusted alpha levels of p = .017. As seen in Figure 4.11, impulse was significantly smaller in the dry condition than in the wet 180^o condition and the wet 120º condition. There was no significant difference in impulse between the 180º and 120º rotation conditions. (impulse data can be found in Table 4.8).

Table 4.8: Descriptive statistics for impulse, NLFDE.

Condition	Analysis	Kolmogorov-Smirnov Test Statistic	Mean (kg*s)	Standard Deviation	Standard Error	Test Statistic
Dry	-	D_{29} = .091, p = .200	1.66	0.58	0.11	-
Wet 180º	-	D_{29} = .224, p = .001*	4.93	1.33	0.81	-
Wet 120º	-	D_{29} = .219, p = .001*	6.14	3.63	0.67	-
-	Freidman's ANOVA	-	-	-	-	$\chi^2_F(2) = 35.00, p < .001$*
-	Dry*180	-	-	-	-	z = -4.690, p < .001*, r = -.58
-	Dry*120	-	-	-	-	z = -4.68, p < .001*, r = .60
-	180*120	-	-	-	-	z = -2.37, p = .017, r = .30

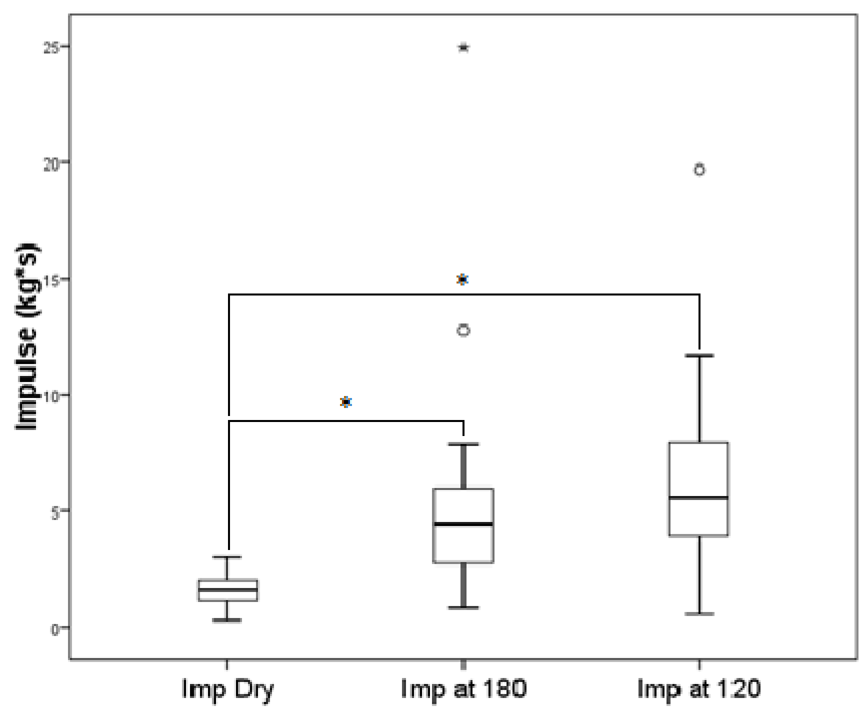

Figure 4.11: Comparison of impulse generated across the three test conditions when using the NLFDE.

4.2.2 Normal Upper Far Dynamic Hand.

Impulse in the dry condition was normally distributed while both impulse in the wet 180º rotation condition and the 120º rotation condition were not. After visually examining the boxplots, it was concluded that no outliers existed in the dry condition while outliers existed in both the wet 180º and 120º rotation conditions. Freidman's ANOVA was used to analyze the data (Field, 2009). The results of Freidman's ANOVA indicated that a significant difference existed between impulse across the dry, wet 180º, and wet 120º conditions. To examine the strength of the differences, a Wilcoxon signed rank test was used with Bonferroni adjusted alpha levels of p = .017. As seen in Figure 4.12, impulse was significantly smaller in the dry condition than in the wet 180º rotation condition and the wet 120º condition. There was no significant difference in impulse generated between the 180º and the 120º rotation conditions (impulse data can be found in Table 4.9).

Table 4.9: Descriptive statistics for impulse, NUFDH.

Condition	Analysis	Kolmogorov-Smirnov Test Statistic	Mean (kg*s)	Standard Deviation	Standard Error	Test Statistic
Dry	-	$D_{(29)}$ = .132, p = .200	0.49	0.07	0.01	-
Wet 180º	-	$D_{(29)}$ = .173, p = .026*	3.39	2.97	0.55	-
Wet 120º	-	$D_{(29)}$ = .202, p = .004*	4.88	5.07	0.94	-
-	Freidman's ANOVA	-	-	-	-	$\chi^2_F(2)$ = 36.92, p < .001*
-	Dry*180	-	-	-	-	z = -4.78, p < .001*, r = -.62
-	Dry*120	-	-	-	-	z = -4.70, p < .001*, r = -.62
-	180*120	-	-	-	-	z = -0.463, p = .655, r = -.06

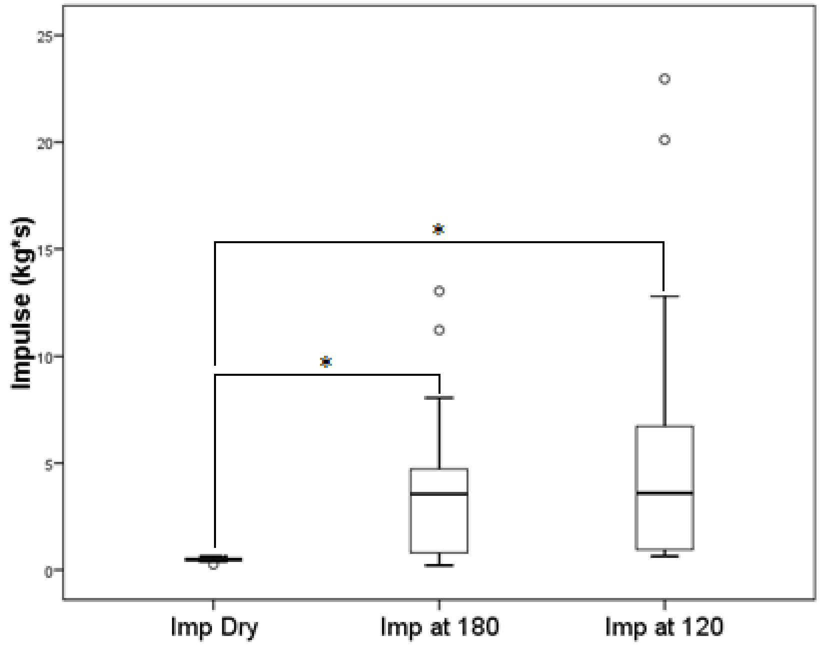

Figure 4.12: Comparison of impulse generated across the three test conditions when using the NUFDH.

4.2.3 Stroke Lower Near Dynamic Elbow.

According to the Kolmogorov-Smirnov test, impulse in the dry, wet 180º, or 120º were all non-normally distributed. Additionally, after visually examining the boxplots, several outliers were detected for all three conditions. The results of Freidman's ANOVA indicated that a significant difference existed between impulse in the dry, wet 180º and wet 120º conditions. To examine the strength of the differences a Wilcoxon Signed Rank Test was used with Bonferroni adjusted alpha levels of p = .017. As seen in Figure 4.13, impulse was significantly smaller in the dry condition than in the wet 180º rotation condition and the wet 120º condition. However, there was no significant difference between impulse generated during the 180º and the 120º rotation conditions (impulse data can be found in Table 4.10).

Table 4.10: Descriptive statistics for impulse, SLNDE.

Condition	Analysis	Kolmogorov-Smirnov Test Statistic	Mean (kg*s)	Standard Deviation	Standard Error	Test Statistic
Dry	-	$D_{(25)} = .245$, $p < .001$*	3.67	2.88	0.58	-
Wet 180º	-	$D_{(25)} = .175$, $p = .047$*	6.04	5.59	1.12	-
Wet 120º	-	$D_{(25)} = .240$, $p = .001$*	7.88	6.33	1.27	-
-	Freidman's ANOVA	-	-	-	-	$\chi^2_F(2) = 12.56$, $p = .001$*
-	Dry*180	-	-	-	-	$z = -2.54$, $p < .013$*, $r = -.34$
-	Dry*120	-	-	-	-	$z = -3.11$, $p = .001$*, $r = -.44$
-	180*120	-	-	-	-	$z = -1.06$, $p = .300$, $r = -.15$

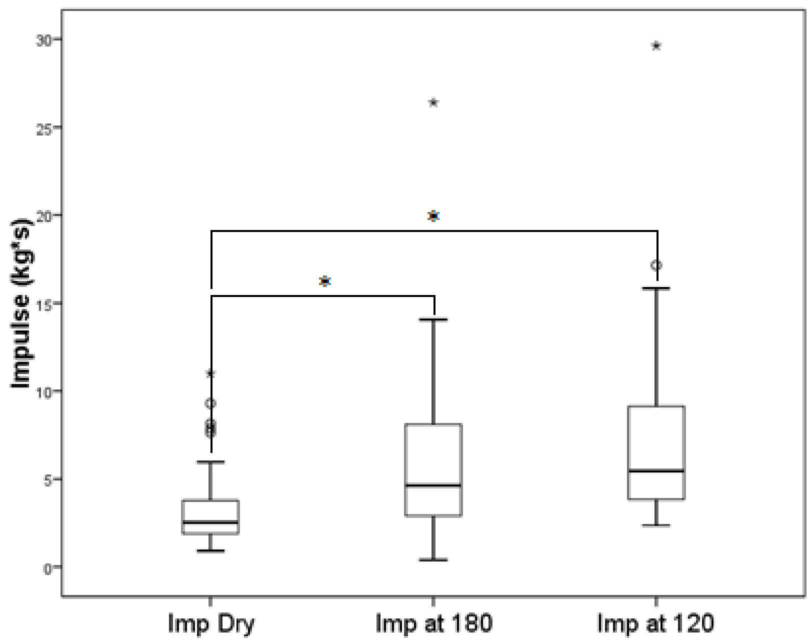

Figure 4.13: Comparison of impulse generated across the three test conditions when using the SLNDE.

4.2.4 Stroke Upper Near Dynamic Hand.

Impulse in the dry condition and the wet 120º rotation condition were normally distributed, while impulse in the wet 180º rotation condition was not. A visual examination of the relevant boxplots revealed that outliers existed in the wet 180º rotation condition. The results of Freidman's ANOVA indicated that a significant difference existed between impulse in the dry, wet 180º and wet 120º conditions. To examine the strength of specific differences a Wilcoxon Signed Rank Test was used with Bonferroni adjusted alpha levels of p = .017. As seen in Figure 4.14, impulse was significantly smaller in the dry than in the wet 180º rotation condition and the wet 120º rotation condition. There was no significant difference in impulse between the wet 180º and wet 120º rotation conditions (impulse data can be found in Table 4.11).

Table 4.11: Descriptive Statistics for Impulse, SUNDH.

Condition	Analysis	Kolmogorov-Smirnov Test Statistic	Mean (kg*s)	Standard Deviation	Standard Error	Test Statistic
Dry	-	$D_{(24)} = 0.136$, $p = .200$	0.52	0.06	0.01	-
Wet 180º	-	$D_{(24)} = 0.179$, $p = .046$*	6.69	5.80	1.18	-
Wet 120º	-	$D_{(24)} = 0.112$, $p = .200$	4.70	3.48	0.71	-
-	Freidman's ANOVA	-	-	-	-	$\chi^2_F(2) = 24.25$, $p < .001$*
-	Dry*180	-	-	-	-	$z = -4.36$, $p < .001$*. $r = -.60$
-	Dry*120	-	-	-	-	$z = -3.91$, $p < .001$*, $r = -.56$
-	180*120	-	-	-	-	$z = -1.63$, $p = .107$, $r = -.24$

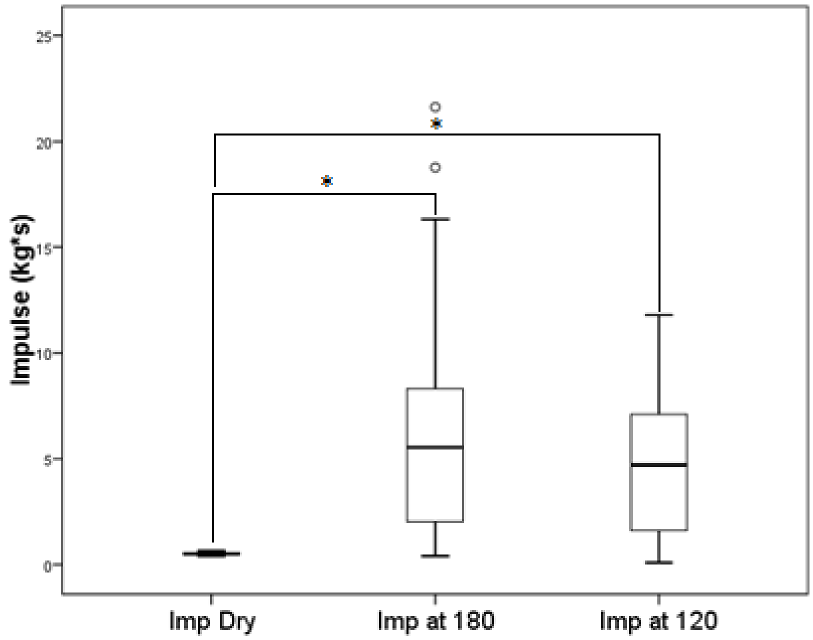

Figure 4.14: Comparison of impulse generated across the three test conditions when using the SUNDH.

4.2.5 Aisle Lower Near Static Hand.

Impulse in the dry condition, impulse in the wet 180º condition, and impulse in the wet 120º condition were all non-normally distributed. To detect possible outliers, boxplots were visually examined and revealed that outliers were present for all three conditions. The results of Freidman's ANOVA indicated that there was no significant difference between impulse in the dry, wet 180º and wet 120º conditions. As the ANOVA was non-significant, no post-hoc testing was conducted (impulse data can be found in Table 4.12).

Table 4.12: Descriptive Statistics for impulse, ALNSH.

Condition	Analysis	Kolmogorov-Smirnov Test Statistic	Mean (kg*s)	Standard Deviation	Standard Error	Test Statistic
Dry	-	$D_{(34)} = 0.197$, $p = .002$*	24.36	26.19	4.49	-
Wet 180º	-	$D_{(34)} = 0.315$, $p < .001$*	13.24	11.78	2.02	-
Wet 120º	-	$D_{(34)} = 0.224$, $p < .001$*	15.09	15.83	2.72	-
-	Freidman's ANOVA	-	-	-	-	$\chi^2_F(2) = 3.77$, $p = .149$

4.2.6 Aisle Lower Near Dynamic Hand.

Impulse in the dry, 180º and, 120º rotation condition were all non-normally distributed. In addition, after visually examining the relevant boxplots, outliers were detected for all three conditions. The results of Freidman's ANOVA indicated that there was a significant difference between impulse in the dry, wet 180º, and wet 120º conditions. To examine the strength of differences between the conditions a Wilcoxon Signed Rank Test was used with Bonferroni alpha levels of $p = .017$. As seen in Figure 4.15, impulse in the dry condition was significantly smaller than impulse in the wet 180º condition and the wet 120º condition. There were no significant differences in impulse between the wet 180º and wet 120º conditions (impulse data can be found in Table 4.13).

Table 4.13: Descriptive statistics for impulse, ALNDH.

Condition	Analysis	Kolmogorov-Smirnov Test Statistic	Mean (kg*s)	Standard Deviation	Standard Error	Test Statistic
Dry	-	$D_{(31)} = 0.304$, $p < .001$*	1.59	2.05	0.37	-
Wet 180º	-	$D_{(31)} = 0.303$, $p < .001$*	6.86	5.30	0.95	-
Wet 120º	-	$D_{(31)} = 0.294$, $p < .001$*	7.99	5.92	1.06	-
-	Freidman's ANOVA	-	-	-	-	$\chi^2_F(2) = 45.16$, $p < .001$*
-	Dry*180	-	-	-	-	$z = -4.94$, $p < .001$*, $r = -.62$
-	Dry*120	-	-	-	-	$z = -4.69$, $p < .001$*, $r = -.59$
-	180*120	-	-	-	-	$z = -1.90$, $p = .058$, $r = -.24$

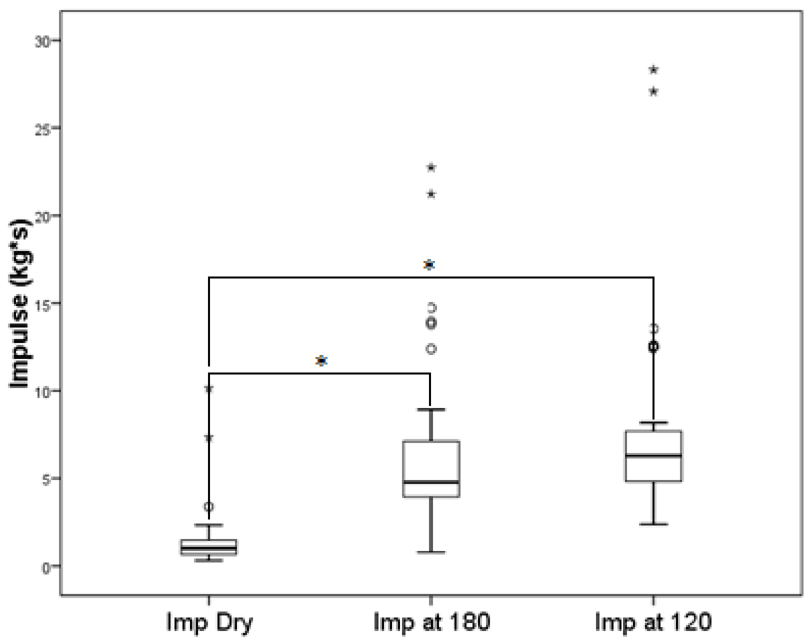

Figure 4.15: Comparison of Impulse generated across the three test conditions when using the ALNDH.

5.0 Discussion

The results of this thesis clearly show that when using strikes that require a large range of motion, the water influences the ability of a participant to generate sufficient load to successfully jettison the window. Strikes which utilize a small range of motion performed much better in the wet conditions with failure rates and loads minimally affected by the condition.

5.1 NUFDH and SUNDH

When considering the influence of load and impulse on failure rates, it is best to begin with the dynamic hand strikes in the window seat because, as seen in Table 4.1 these trials showed the largest discrepancy between the dry and wet condition failure rates. Despite failure rates in the 20-30% range for the dry condition for both the NUFDH and the SUNDH, the failure rates in the wet condition for these strikes was absolute (100% for all trials).

For both NUFDH and the SUNDH, significant load decreases were observed between the wet and dry conditions while impulse increased significantly (Tables 4.3, 4.5, 4.9, 4.11). This initially suggests that impulse is directly related to failure rate while load is inversely related to failure rate. While it is not entirely surprising that an increase in load will reduce the chance of failure, it highlights the relationship that exists between load and impulse. Given that impulse is the product of load (force) and time, and load was found to significantly decrease in wet trials 2, 4, 8, and 10, it can be concluded that the time, which the hand remains in contact with the window is longer during the wet conditions.

Considering the mechanism of force and impulse production for the NUFDH and SUNDH allows for an explanation of the observed load decreases. The mechanism of load and impulse generation for the NUFDH and SUNDH is similar to the reverse punch. Several studies (Gulledge & Dapena, 2008; Nakano et al., 2014) have noted that the reverse punch relies on a large range of motion to develop force and impulse. Given the loads recorded during the dry trials, this mechanism is applicable. Also, the observed significant decreases seen in load for the NUFDH and SUNDH wet conditions suggest that the natural resistance of water may actually cause a loss of velocity over a large range of motion. Toussaint and Beek (1992) suggest that during swimming, there are three drag components that act against forward motion: pressure drag, friction drag and wave making resistance. While pressure drag and wave making resistance are not applicable to this thesis, friction drag is. Toussaint and Beek (1992) suggest the magnitude of friction drag experienced during a particular motion "depends on the friction between skin and water" (p. 9). While it is unknown how the wearing of a survival suit influences friction drag force, given that it is looser than a participant's skin, it is likely that friction drag will be at least equal to, if not greater than that experienced with skin to water contact. Given that friction drag constantly opposes movement through the water, it is not surprising that load experienced a significant decrease during the wet NUFDH and SUNDH trials. As the arm and fist moved through the long range of motion (which is beneficial in-air), friction drag constantly opposed the movement slowly decreasing the load of the strike. Once the segment finally made contact with the simulated window, the load had been diminished to such a degree that it was impossible for any participant to jettison it (Table 4.1).

In addition, Sorensen et al. (1996) suggested movements similar to the NUFDH and SUNDH occur in a "proximo-distal sequence" where the proximal segments of the body (upper arm) accelerate while the distal segments lag behind. Given that the NUFDH and SUNDH experienced decreases in load ranging from 70-77% between the dry and wet conditions, it is likely that friction drag negatively influenced this proximo-distal sequence of motion. The influence of the friction drag is seemingly confirmed by the large *z*-scores, *t*-statistics and *r*-values seen for the post hoc testing conducted on the NUFDH and SUNDH (Tables 4.3, 4.5, 4.9, 4.11) indicating that the testing condition had a significant impact on the observed results. It is possible that while the upper arm segment acceleration may be unaffected due to its proximity to the prime movers for the action (deltoid and triceps muscles) friction drag may further slow the distal segment acceleration resulting in the observed lower load values and as a result, higher failure rates.

Taken as a whole, these factors account for the increase seen in impulse. As the load of the strike was diminished to a point where jettisoning the window was impossible, it is likely that once the fist made contact with the window, a certain degree of static pushing occurred. While impulse was seen to increase, these results suggest that it is not a significant determinant of success. While impulse does increase with failure rate for the NUFDH and SUNDH, a relationship between the two factors likely does not exist as the increase in impulse was secondary to failure, namely insufficient load to jettison the window resulted in increased pushing which in turn increased the impulse.

5.2 NLFDE and SLNDE

The failure rates for the NLFDE and the SLNDE did not vary as much as the NUFDH and the SUNDH (Table 4.1). Also, opposed to the NUFDH and the SUNDH, no significant difference existed in loads across the three conditions for the SLNDE (Table 4.4) while the NLFDE was significant for the difference between two of the conditions (Table 4.2). Given though that only one of a possible four comparisons resulted in a significant result likely indicates that load remained virtually unchanged across the test conditions. Interestingly, impulse was significantly different for all comparisons (Tables 4.8, 4.10). Chang et al. (2011) suggested that the type of strike used influences the ability to generate power (and thus load). Given the functional differences between the hand and elbow strike types, differing, loads, impulses and failure rates are logical. While the dynamic hand strike is most similar to the reverse punch, the elbow strike is functionally similar to the power punch. As Gulledge and Dapena (2008) noted the reverse and power punch had similar impulses but the power punch required only a small range of motion to develop sufficient momentum.

The key reason for the similar performance of the NLFDE and SLNDE in the dry and wet conditions is the smaller range of motion that it requires to develop load and impulse. Due to friction drag, the NUFDH and SUNDH required a significant amount of load to move through the water towards the target (Window). The NLFDE and SLNDE however, require only a small range of motion to develop load and impulse. Given that friction drag constantly opposes motion through the water, it is intuitive that a shorter range of motion would be beneficial in the conservation of load and impulse. This is reflected in the non-significant difference in loads observed for the NLFDE and SLNDE. Additionally, the non-significant Freidman's ANOVA for the SLNDE and the small *z*-scores and *r*-values for the post hoc testing conducted on the NLFDE (Tables 4.2, 4.4) indicate that the testing condition did not significantly influence the ability of the participants to generate load. In addition, the elbow strike likely does not undergo proximo-distal segment acceleration as the elbow is part of the proximal segment of the arm (upper arm) during this type of strike. Finally, the point of contact during the NLFDE and SUNDE strikes (elbow itself) is closer to the prime movers (triceps and deltoids) for the strike than the point of contact is for the NUFDH or SUNDH.

While load was seen to not be significantly different for wet trials 1, 3, 7, and 9 impulse did increase (Tables 4.8, 4.10). As with the NUFDH and SUNDH, larger impulses indicate that time of contact with the window was longer during the wet conditions. As suggested for the NUFDH and SUNDH, it is possible that if the window did not jettison immediately on contact, then some degree of pushing was used to successfully jettison the window. This provides a viable explanation for the difference in impulse that existed for the NLFDE and SLNDE. However, given that failure rates for wet trials 1, 3, 7, and 9 exhibited minimal variation between the dry and wet conditions (Table 4.1) but impulse was significantly different, it is likely that impulse did not influence the participants' likelihood of success for these trials.

5.3 ALNDH

Much like the NUFDH and the SUNDH, this strike showed a significant decrease in load and a significant increase in impulse between the dry and wet conditions. However, this strike is actually quite different than the NUFDH and the SUNDH. For example, the decrease in load between the dry and wet conditions is less dramatic. While the loads for the NUFDH and SUNDH decrease between 70-77% when comparing dry to wet, the ALNDH decreases 32-33%. In addition, there was minimal variation in the failure rate for ALNDH (Table 4.1). Interestingly, the ALNDH data for both load and impulse is more similar to the NLFDE and the SLNDE than it is to the NUFDH and the SUNDH. Chang et al. (2011) suggested that the strike type used will influence the ability to generate power (Load) and this provides an explanation for this observation.

Consider that, functionally, the ALNDH is more similar to the NLFDE and SLNDE than it is to the NUFDH and the SUNDH. While the NUFDH and SUNDH undergo "proximo-distal segment" acceleration (Sorensen et al., 1996), over a large range of motion to develop momentum for the strike (Gulledge & Dapena, 2008), the ALNDH does not. Instead, functionally, this strike is essentially a power punch. As Gulledge and Dapena (2008) noted, advocates of the power punch contest that rigidity between the fist and body allows for the rapid generation of force (load) and impulse seen with the strike. As this strike was conducted in a manner similar to the power punch, it is not surprising that the failure rate was unchanged. While the NUFDH and SUNDH essentially wasted load to overcome friction drag over a large range of motion when in the water, the ALNDH required only a small range of motion to develop load and impulse and the smaller range of motion meant minimal wastage of developed load as the magnitude of the friction drag during the ALNDH was less than the magnitude of the friction drag for the NUFDH and SUNDH.

Despite the differences that exist between the ALNDH and the NUFDH and SUNDH, load for the ALNDH still decreased significantly between the dry and wet conditions. Given the relationship between load and impulse, it is not surprising that impulse increased significantly. Clearly the time of contact with the window was longer during the wet trials suggesting again, that some degree of static pushing occurred. However, like the NLFDE and the SLNDE, this suggests that impulse is not a significant determinant of success. While the difference in failure rate for the dry and wet ALNDH trials was minimal, the difference in impulse was significant. The fact that failure rate did not vary but impulse did suggests that impulse is not an important contributor to jettison success. Additionally, while, based on failure rates, friction drag appears to be less detrimental to jettison success when using the ALNDH than it was during the NUFDH or SUNDH, the large *t*-statistics and *r*-values for the ALNDH which compared the wet and dry conditions (Table 4.7) still indicate that the testing condition did influence the ability of participants to generate load.

5.4 ALNSH

The ALNSH represents a unique strike in this study as it is a static push, there is no dynamic action for this strike. Of all the strikes tested, this strike exhibited the least variation in load (Table 4.6), impulse (Table 4.12) and failure rate (Table 4.1) between the dry and wet conditions with no significant difference in load or impulse. Given the mechanics of this strike however, this is not surprising. While other strikes showed greater impulse, and thus greater time of contact and likely greater difficulty jettisoning the window, the non-significant difference in impulse between the conditions for the ALNSH likely indicate that jettison difficulty was the same in the wet condition as it was in the dry condition. This is likely due to the effect of friction drag on the ability of a participant to generate sufficient load to jettison the window. As seen thus far, strikes with a large range of motion such as the NUFDH and SUNDH exhibited significant drops in load while their failure rates were absolute in the wet conditions. The NLFDE, SLNDE and ALNDH performed better in the wet condition due to the fact that the range of motion for these strikes was smaller than that of the NUFDH and SUNDH. This suggests that the magnitude of the friction drag is directly related to the range of motion. Thus, it is logical to conclude that a static strike, with an effective range of motion of zero should experience no friction drag.

This is confirmed when considering the load and impulse data for the ALNSH, as there was no significant difference in load or impulse for the trials (Tables 4.6, 4.12). A non-significant difference in load and impulse is unsurprising for this condition for an additional reason too. When utilizing the NULDH, SUNDH, NLFDE, SLNDE and ALNDH, the window is hit with a certain load and impulse which may be higher or lower than the threshold necessary for jettison. However, the ALNSH, being a push will cause the window to be jettisoned at or near the threshold necessary for successful jettison every time. Thus, the load and impulse should be similar between wet and dry conditions.

5.5 Influence of Rotation Angle on Load and Impulse

In addition to the influence of load and impulse on the likelihood of performance success for the jettison task, this study aimed to determine if a significant difference existed in load and impulse between the 180º and 120º rotation conditions. However, one of the interesting findings of the study was in fact a non-significant result. Load, generated during jettison attempts, does not appear to be influenced by the angle of rotation of the METS^{TM}. No significant difference existed in load between the 180º and 120º conditions for any of the six trials, which were tested in the wet condition (Table 3.4). While it was hypothesized that there would be a significant difference (Section 1.2) between the 180º and 120º conditions due to the different angle that the strike was delivered at, this was not supported by the results.

Given that impulse is the product of load and time, and load remained unchanged between the 180º and 120º condition for trials 1-6 in the wet testing, it is not surprising that impulse was not significantly different either. Interestingly, the fact that the participants had to push the window in an upward direction (against gravity) did not influence the impulse, which they were able to generate. While this is a non-significant result, it represents an interesting finding. While the difference between the conditions was not significant for load or impulse, the fact that angle does not significantly influence either variable is an important result for this study. Taber (2014), Brooks et al. (2008), and Clifford (1996) found that when the rotorcraft makes contact with the water's surface, they often invert to some degree. Given that the amount of rotation, which they undergo differs between ditching events, it is important to know if it is a factor which will influence the ease of egress for passengers. While these results were obtained from testing conducted in a simulated environment, they are important as they suggest that the degree of rotation does not negatively impact the ability of a participant to produce load or impulse on the window.

5.6 Limitations of the Study

As with any research study, limitations will exist in the design and implementation of the experiment. The major limitation which existed in the larger study was the use of a simulated environment for data collection. While the data was collected in a simulated environment which may not exactly replicate the real-world environment, collecting data from real helicopter ditchings would obviously be unethical, impractical, and dangerous. Thus, the simulated environment in which the data was collected was the best option available for the larger study. Secondly, the effect of learning is a consideration in the repeated measures study design. While it is possible that learning effects occurred, the sheer number of trials which participants completed would likely negate learning effects. For example, each participant performed up to 87 jettison attempts (29 trials times three attempts for each) plus 2 practice and 12 testing trials (with 3 attempts for each) in the wet condition for a total of 125 possible strikes of the simulated window. With this volume of training, learning effects are likely to have diminished to a point that they would be negligible beyond the initial trials. Additionally, the secondary data analysis research design itself has been criticized by authors including Cheung and Phillips (2014). Cheung and Phillips (2014) suggested that when data is not originally gathered for the purpose of answering the author’s research question, reliability and validity of the results may be limited.

5.7 Summary

The aim of this study was to determine how the characteristics of the impulse profile influenced the likelihood of success during an attempt to jettison the simulated in-cabin push-out window on a simulated Sikorsky S-92. Using a secondary data analysis research design, load and impulse data were calculated and compared to failure rates for six trials, which were conducted in three conditions (Dry, Wet 180º, and Wet 120º). While Load represents an important consideration when analyzing a jettison attempt, impulse is not significantly related to performance success. Load generated during a jettison attempt may be influenced by a wide range of factors, most importantly, strike type. As Chang et al. (2011) noted, strike type is a key determinant of power output which is directly related to load. The results of this study indicate that while a large range of motion may be beneficial to load generation in air (Gulledge & Dapena, 2008; Nakano et al., 2014), it is detrimental when the strike is performed in water. As Toussaint and Beek (1992) stated, when a body moves through water it is resisted by three types of drag force. Most applicable to this thesis is friction drag, the drag, which results from the friction between skin and water. When a strike moves through the water, the small but uniform drag force will resist the motion. When the strike has a small range of motion, like the NLFDE, SLNDE and ALNDH, the effect of friction drag is not reflected in failure rates. However, when the strike must move through a large range of motion such as the NUFDH and SUNDH, the effect is pronounced with failure rates for both of these strikes being absolute in the wet condition.

Interestingly, load and impulse are not influenced by the angle of rotation of the METS^{TM}. This suggests that while the angle at which the fuselage of a rotorcraft involved in a ditching event is variable, it should not influence the ability of passengers to generate load and, due to the relationship between them, impulse. However, as only two angles were tested, it is impossible to determine a definitive conclusion from the data.

Finally, limitations are present in the research design and data collection. While learning effects may explain some of the variation seen in the data, the sheer number of attempts that participants were given should negate the effect of learning in the larger study. Additionally, while the use of a secondary data analysis may result in the loss of reliability and validity (Cheung & Phillips, 2014), the larger study still collected force-time curve data, which allows for the determination of load and impulse.

6.0 Conclusion

This study set out to examine how load and impulse, generated during an attempt to jettison a simulated S-92 push-out window influenced the likelihood of success for the jettison task. To date, no previous research has explored how factors such as load or impulse influence the likelihood of successfully jettisoning the push-out windows on the S-92. On the Sikorsky S-92, the ten in-cabin push-out windows are unregulated by governmental institutions such as the FAA, CAA and TC. The CAA does provide some guidance on the window, but when compared to the specificity of the regulations, which govern designated emergency exits, this guidance is vague. To date, only one study (Taber & Sweeney, 2014) has quantitatively examined the push-out style in-cabin exits on a simulated S-92 and no studies have examined the windows on the actual aircraft (Taber & Sweeney, 2014). In an effort to provide a meaningful addition to the knowledge base on the subject, this study aimed to determine "How does the load and impulse, generated during an attempt to jettison a simulated S-92 push-out exit influence the likelihood of success?"

To answer the research question, three hypotheses were tested. First, the study tested the hypothesis that load and impulse generated during in-air jettison attempts will be significantly different than the load and impulse generated during wet condition jettison attempts. This hypothesis was supported by the results as load and impulse were shown to be significantly different for the majority of the trials conducted (Sections 4.1, 4.2). Secondly, the thesis tested the hypothesis that the load and impulse would be significantly different for corners of the window which were tested. This hypothesis was supported by the results as the load and impulse for three corners (Lower Far, Upper Near, and Upper

Far) were significantly different between the dry and wet conditions. Interestingly, the loads for the SLNDE (Table 4.4) and ALNSH (Table 4.6) and the impulse for the ALNSH (Table 4.12) were not significantly different between the conditions. Finally, the study also tested the hypothesis that the load and impulse generated with the METS™ rotated to 180º will be significantly different from the load and impulse generated with the METS™ rotated to 120º. Based on the results, this hypothesis is rejected as neither load nor impulse were significantly different between the two conditions for any of the trials tested (Sections 4.3, 4.4).

Given the evidence ascertained by the testing of these hypotheses, several important conclusions were made. First, load is directly related to success of a jettison attempt. This was concluded as nearly all of the analyses conducted on load and failure rate were inversely related. Second, impulse is not a significant predictor of success. While, impulse was significantly different for five of the six trials, the failure rates were not consistently different. Thus, it is concluded that impulse is not critical to success in this study. However, increasing impulses highlights the relationship between load and impulse, that is, impulse is the product of load and time. In the wet trials, loads were seen to decrease, but impulse was seen to increase. The likely mechanism is that when the window did not jettison immediately on strike contact, participants initiated some degree of pushing, which increased the time of the action and thus the impulse. However, as noted, this increased pushing did not influence the observed failure rates in this study. Interestingly, the same factors which influence power and force in karate and boxing appear to influence load of the jettison task. Decreases in load during the wet trials for strikes the NUFDH and SUNDH can be explained by the large range of motion of the strike and the negative effect of friction drag over that range. This was confirmed by the ALNSH as its range of motion was effectively zero and as a result, it was the most robust in terms of similarity of load between wet and dry conditions.

Interestingly, the corner struck may influence the load generated between the dry and wet conditions. Most interesting perhaps is the finding that there was a lesser degree of difference for strikes in the lower near corner. While success of the jettison task depends on an intricate interplay of factors, this suggests that the lower near corner, perhaps due to its proximity to the participant, may be more robust in terms of load consistency.

The fact that angle of seat rotation did not influence load or impulse in this study represents an interesting finding. The results suggest that perhaps fuselage orientation during a ditching event may not influence the ability of a passenger to generate sufficient load and impulse to jettison the window. However, as only one additional angle was tested on one particular type of simulator, a generalization to all helicopter ditchings/orientations would be impractical.

While it is possible that many factors could influence whether or not an attempt to jettison a simulated in-cabin window will succeed, this study explicitly focused on load and impulse. In an effort to gain more knowledge on factors that may influence success during this task, the following may be considered for future research:

1) As the data collection allowed the participants the use of a dive mask, and the analyses relied on strikes of a particular corner, future research may wish to considered whether a discrepancy exists in a person's ability to strike the window in that particular location with and without the use of the mask.
2) As this study speculates that proximo-distal segment acceleration and a long range of motion negatively influence strikes in-water, future research may wish to determine if in fact they do through the use of kinematic analyses.

As the in-cabin push-out window was only examined in one previous study, the goal of this study was to attempt to aid a small piece to the knowledge base surrounding the subject. Through the examination of its research question and hypotheses, this study has found that load, applied to the simulated push-out window, does influence the likelihood of successfully jettisoning a simulated in-cabin push-out on a Sikorsky S-92. From the analyses, it is concluded that load is directly related to success of the jettison task. It is hoped that these findings will inform trainers, regulators and manufacturers in a way that will improve occupant survivability of future ditching events.

7.0 References

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